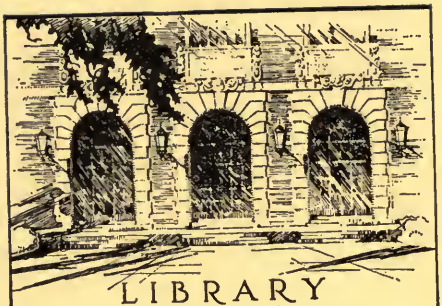

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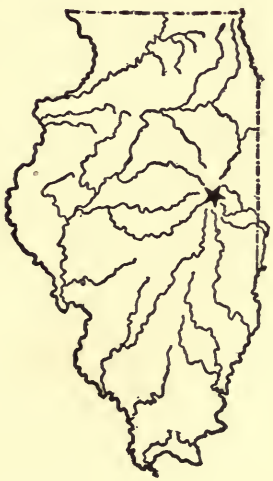
THE DIGESTIBILITY AND METABOLIZABLE ENERGY OF SOYBEAN PRODUCTS FOR SHEEP

By T. S. Hamilton, H. H. Mitchell, and
W. G. Kammlade



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THE DIGESTIBILITY AND METABOLIZABLE ENERGY OF SOYBEAN PRODUCTS FOR SHEEP

By T. S. Hamilton, H. H. Mitchell, and W. G. Kammlade*

Since the introduction of soybeans into Europe in 1875 there has been an increasing interest in the adaptation of this valuable legume to the European and American systems of agriculture. The plant has been used as a leguminous crop in the corn belt only comparatively recently, but it is rapidly becoming more popular, not only because of its value as a means of maintaining soil fertility, but also because of the high percentage of costly nutrients it contains.

With the increased supply of soybeans there have developed new uses for the products obtained from them. Some of these products are rapidly taking the place of more expensive feeds in the rations of farm animals and are being put to new uses in the industries. While the beans from the soybean plant form a standard article of diet for humans in the Orient, none of the various dishes which may be prepared from them have found great favor in this country. However, with the increasing use of soybeans and soybean products for livestock, a demand has arisen for information concerning their nutritive value. The investigations reported herein were undertaken, therefore, in order to determine the digestibility and metabolizable energy of soybean hay, soybean straw, whole soybeans, and soybean oil meal. In order to obviate what was thought to be one of the greatest faults with most previous investigations along these lines, that is, the use of too few experimental animals, it was decided to determine the digestibility and metabolizable energy for each feed on each of 12 sheep, a number three times as large as has heretofore been used in any single digestion experiment with soybean products.

REVIEW OF PREVIOUS WORK

Investigations concerned with the feeding value of the various parts of the soybean plant were reported by Weiske, Dehmel, and Schulze[1*] in 1879. These investigators determined the digestibility of the nutrients in soybean straw and in soybean pods for farm animals. In 1883 the digestibility of soybean straw was again determined by Weiske, Kennepohl, and Schulze,[2*] and in 1886 Kellner[3*] determined the digestibility of soybean seed and of soybean hay.

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In America there have been comparatively few digestion experiments with soybean products. No digestion experiments with soybean oil meal or with soybean straw have been reported. Of three digestion trials on soybean hay, the first was that of Sturtevant[4*] in 1884. In this experiment the hay was fed, combined with corn meal and wheat bran, to two cows during a six-day trial. The feed intake was constant for only three of the six days and the feces were collected for one day only. The digestibility of the hay was calculated indirectly from the nutrients digested from the combined ration and from average coefficients of digestibility for corn meal and wheat bran obtained from German tables. The second American trial was reported in 1894 by Emery and Kilgore,[5*] who fed soybean hay alone to a cow and a goat. The collection period, which followed a suitable preliminary period, was of five days' duration. The third and last digestion trial with soybean hay was that of Lindsey, Beals, and Smith,[6*] who determined the digestibility of the hay when fed with English hay to two sheep.

The digestibility of soybean seed has been determined five times with ruminants and once with swine. In all, 5 swine and 17 ruminants (16 sheep and 1 steer) were used, and six different samples of beans were tested. Lindsey, Smith, and Holland[7*] in 1894 determined the digestibility of the nutrients of ground soybeans when fed with English hay, using two sheep. In 1895 the digestibility of soybeans fed with timothy rowen hay was determined in two trials, with four sheep in each, by Phelps and Woods.[8*] The only experiment concerned with the digestibility of soybeans by steers was reported in 1901 by Willard and Clothier.[9*] In this trial soybean meal was fed with kafir corn stover to a steer. Lindsey in 1903[10*] and again in 1904[11*] obtained digestion coefficients on ground soybeans when fed with English hay, using two sheep in each of these studies. The digestibility of soybeans by swine has been determined by Forbes, Beegle, Fritz, and Mensching.[12*] The soybeans were fed with corn to 5 swine.

The digestibility of soybean forage when fed green to sheep has been determined on seven different samples reported in five investigations. Three of these investigations were carried out at the Connecticut (Storrs) Station and the other two at the Massachusetts (Hatch) Station. In the Connecticut investigations reported by Phelps and his coworkers,[8, 13, 14*] 12 sheep were used in the determination of the digestibility of the green soybean forage, fed alone, at five different stages of growth from early bloom until seeds formed. In the two investigations by Lindsey and his coworkers[11, 15*] at the Massachusetts Station, 6 sheep were used and the forage was fed with English hay.

The digestibility of soybean silage has been the subject of three investigations. Emery and Kilgore[16*] at the North Carolina Station in 1892, using two goats, were the first to carry out such an experiment.

In 1895 the digestibility of soybean silage by four steers was studied by Hopkins[17*] at the Illinois Station and in 1903 Mooers[18*] of the Tennessee Station made a similar study using 3 steers.

Rations containing soybean products have also been studied in a few cases without any attempt to interpret them with regard to the digestibility of the soybean product alone. In 1895 Phelps and Woods[8*] reported the results of two investigations, in each of which 4 sheep were used. In the first the ration contained .5 pound soybean meal and 1 pound timothy rowen hay, and in the second .75 pound soybean meal and 1.5 pounds hay. In 1896 the Massachusetts (Hatch) Station[19*] carried out two investigations with sheep. In one of these the digestibility of corn and soybean silage in the ratio of 2 to 1 was studied, and in a second, the digestibility of millet and soybean silage. In 1904 Bartlett[20*] reported, among a large number of digestion experiments with sheep and steers, three trials with rations containing soybean silage. In one trial two sheep were used and soybean and corn silage (9:14) was fed alone, one sheep receiving 3,000 grams daily and the other 2,000 grams. In a second trial the same silage was fed to a steer, and in a third trial the silage was fed with some hay to 2 steers.

The details of all the above mentioned investigations will be found in the Appendix, Table 22, which gives a compilation of all American digestion experiments on soybean products to date, including those reported in this bulletin.

No reports of investigations on the metabolizable energy of soybean products have been found in the literature.

Critical Consideration of Results of Previous Investigations

With the possible exception of those experiments in which green soybean fodder and soybean silage were used, most of these experiments are not satisfactory. With what is perhaps the most important soybean product, viz., soybean oil meal, no study has been made.

A brief examination of almost any of the trials in which two or more animals were used will show quite wide variations among the coefficients obtained, this being especially the case when the coefficients have been calculated indirectly, i.e., from those obtained with a mixed ration. Such results indicate the necessity for the use of a larger number of experimental animals and longer collection periods. Collection periods of 5 or 6 days are too short, especially for steers. Naturally, the coefficients obtained for the same feed by different investigators or by the same investigator at different times will vary no less than do those of any one trial. Average coefficients compiled from these data are to be found in several standard publications and are widely used. The value of such averages in the planning of rations cannot be considered satisfactory in view of the objections mentioned, while the application of coefficients obtained from one species of

ruminant to another has not hitherto been shown to be justifiable. One example will be considered in detail to illustrate the questionable value of such average results.

A well-known American compilation of the digestibility of farm feeds[21*] gives the following coefficients for soybean oil meal for ruminants: crude protein 92 percent, nitrogen-free extract 100 percent, ether extract 68 percent, and crude fiber 99 percent. These values are given as the averages of two digestion trials and are taken from Mentzel and Lengerke's "Landwirtschaftliche Kalender,"[22*] which is itself a compilation. While no literature references are given in this German publication, the original investigation from which these values were obtained may be identified as one which Honcamp[23*] carried out in 1909 at the Rostock Agricultural Experiment Station. After first determining the digestibility of a basal feed of clover hay for 2 wethers, this investigator fed each of the wethers a mixed ration of 760 grams of clover hay and 240 grams of "pressed" soybean meal in one period. In a second period one of the two wethers received a ration of 600 grams of clover hay and 200 grams of a sample of "extracted" soybean meal, and in a third period a third wether was fed 700 grams of clover hay and 200 grams of a second sample of "extracted" soybean meal. The results of this investigation are tabulated in Table 1.

TABLE 1.—COEFFICIENTS OF DIGESTIBILITY OF "PRESSED" AND "EXTRACTED" SOYBEAN MEAL (HONCAMP[23*])

	"Pressed" soybean meal			"Extracted" soybean meal		
	Period I			Period II	Period III	Average
	Wether 1	Wether 2	Average	Wether 2	Wether 4	
Organic matter	90.3	96.8	93.6	96.9	96.4	96.6
Crude protein	91.8	93.8	92.8	91.9	91.8	91.9
N-free extract	97.9	107.5	102.7	112.9	98.0	105.4
Crude fat	93.6	92.0	92.8	29.6	105.5	67.6
Crude fiber	16.8	55.4	36.1	68.3	130.4	99.3

The values above quoted are obviously the averages, in whole numbers, of Honcamp's coefficients for the "extracted" soybean meal, coefficients above 100 being quoted as 100. The average coefficients for crude fat and crude fiber, i.e., 68 and 99 respectively, are of little significance since each is the average of two widely varying figures, 68 being the average of 29.6 and 105.5, and 99 being the average of 68.3 and 130.4. The average coefficient for the nitrogen-free extract is 105.4, the individual results being 112.9 and 98.0. Digestion coefficients above 100 result from the fact that the admixture of nitrogenous concentrates, such as soybean oil meal, often increases the digestibility of the nitrogen-free extract of the basal ration, so that the apparent digestibility of this nutrient as computed indirectly for the supple-

mentary feed becomes over 100 percent. Such an impossible result is thus due to the fallacy upon which the method of computation is based, and cannot be used with confidence in computing the digestible nutrients in any other combination of feeds. The substitution of a coefficient of 100 for a larger value thus indirectly computed cannot be considered a solution of the difficulty, since no evidence can be offered that lower coefficients may not be nearer the truth.

The coefficients for crude protein only are in good agreement and, fortunately, crude protein is not only the most abundant but also the most important nutrient in soybean oil meal. The excellent checks for the coefficients of digestibility of organic matter are a fortunate coincidence only.

There can be little criticism of the length of collection periods (10 days) in this experiment, but if the average coefficients obtained are to be used in the computation of rations for other ruminants than the sheep, the possibility of other errors must be considered. Just how great an error is likely to be incurred by using for steers or dairy cows digestion coefficients obtained with sheep is impossible to estimate at the present time. Probably this error would not be great, since in digestion experiments there often are found as great variations between different sheep as between sheep and steers. However, as Bartlett[20*] says (page 204), after a study of the digestibility of a variety of feeds by both sheep and steers, "If sheep are to be used to determine coefficients for bovines, great care should be taken to select strong animals that are good feeders and will eat coarse fodders readily, otherwise results which are too low are likely to be obtained."

Finally, attention should be called to the fact that the digestion coefficients of Honcamp's experiment were obtained on two samples of specially extracted soybean meal. Honcamp's analyses show 1.40 percent crude fat in one sample and 1.80 percent in the second sample, an average of 1.60 percent crude fat. The average percentage of crude fat in 11 samples of extracted soybean oil meal analyzed in this laboratory is 4.64. The average of four analyses of pressed soybean oil meal is 7.31 percent crude fat, making an average of 5.35 percent crude fat in soybean oil meal purchased in Illinois. Henry and Morrison give 6.6 percent crude fat as an average for soybean oil meal, and Lindsey and associates[24*] quote 8.6 percent fat in a sample of soybean oil cake. It is therefore obvious that the two German samples of soybean oil meal were considerably different in fat content from any obtainable in America, and it is quite probable that their digestibility would not be the same as the digestibility of soybean oil meal obtainable in this country. In confirmation of this belief, the differences in the digestibility of pressed and extracted soybean oil meal as determined in Honcamp's experiment may be cited (Table 1).

INVESTIGATION OF 1923

Plan of Investigation

Twelve western lambs weighing from 80 to 100 pounds were used as experimental animals in the first experiment with sheep in 1923. With each sheep the digestibility and metabolizable energy of the following five feeds or rations, corresponding to the five successive periods of the experiment, were determined: (1) soybean hay, (2) soybean straw, (3) oat straw and whole soybeans, (4) oat straw, and (5) soybean straw and soybean oil meal. By making use of the digestion coefficients and the metabolizable energy values for oat straw and for soybean straw obtained in Periods IV and II respectively, the digestibility and metabolizable energy of whole soybeans and of soybean oil meal were calculated in the usual indirect manner from the data obtained in Periods III and V.

The digestion trial for each feed or combination of feeds consisted of a 10-day preliminary period, during which the sheep received the exact ration which they were later to receive during the collection period, and a period of 8 days in the metabolism crates during the last 7 days of which the collections were made. The equipment for making the collections consisted of three Forbes' metabolism crates for swine.[25*] The three sheep grouped together in the tables were in the metabolism crates at the same time.

In Period I soybean hay was fed in the following amounts daily: 910 grams to Sheep 130, 131, and 132; 1,025 grams to Sheep 133, 134, and 135; 1,135 grams to Sheep 137, 138, and 139; and the same to Sheep 136, 140, and 141. In Period II each of the 12 sheep received 1,135 grams of soybean straw. In Period III Sheep 130 to 133 inclusive received 910 grams and Sheep 134 and 135, 811 grams of oat straw, together with 230 grams of whole soybeans; and Sheep 136 to 141 inclusive each received 680 grams of oat straw and 225 grams of whole soybeans. In Period IV each of the 12 sheep received 910 grams of oat straw, with the exception of Sheep 135, which received 779 grams. In Period V each of the 12 sheep was fed 910 grams of soybean straw and 225 grams of soybean oil meal.

The sheep were fed twice daily: in the morning immediately after the collections were made and late in the afternoon. During the period in which whole soybeans were fed, the beans were given first and the sheep allowed to clean these up completely before the oat straw was fed. In the period in which soybean straw and soybean oil meal were fed, the meal was sprinkled over the straw in an attempt to induce the sheep to eat the straw more readily.

The same purchase of Midwest soybeans and of extracted soybean meal served thruout the entire experiment. A sufficient amount of each of the roughages was secured for the entire experiment, but no attempt was made to mix the entire supply of either. The roughages

were weighed to the nearest 10 grams and the concentrates to the nearest 5 grams. Distilled water was kept before the sheep at all times. Salt was available only during the preliminary periods. Samples of feed for analysis were obtained by removing a small quantity of each feed at each weighing.

Collections of excreta were made daily in the morning. The method of collection was very similar to that described by Forbes for the management of these crates.[25*] The feces were not aliquoted, each daily excretion being added to tightly covered 50-pound lard cans until the end of the collection period, when they were ground, mixed, and sampled for analysis. The feces were ground in the fresh condition by putting them once thru a revolving-hammer type of mill with a large-sized screen. This method of preparation completely disintegrated the feces without any grinding or heating effect, so that they could be satisfactorily analyzed in the fresh condition. The daily collections of urine were aliquoted and the aliquots composited for the period. All samples of feces and urine were preserved by refrigeration until analyzed. Refused feed was removed daily, the daily orts combined for the period, dried, and analyzed.

In addition to the usual routine determinations, which were made in accordance with the official methods of the A. O. A. C., the gross energy in all samples was determined by the bomb calorimeter. In making the energy determinations on urine, 100 cc. portions were evaporated at low temperatures under a current of warm air, absorbed on cellulose blocks, and ignited with the cellulose. In this determination no correction was made for material lost on drying.

Experimental Results Obtained in 1923

Digestibility of Soybean Products.—In an investigation such as this an enormous amount of data is obtained, but for the sake of economy of space much of it will be omitted or given only in summarized form. The average percentage composition and gross energy of the rations offered, of the orts, of the rations consumed, and of the feces of each period are given in Table 2. The digestion coefficients of the nutrients consumed in each period were calculated in the usual manner and these are tabulated for each sheep and averaged for each period in Table 3.

From the data obtained on the ration of whole soybeans and oat straw (Period III) and on the ration of oat straw alone (Period IV), the coefficients of digestibility of the nutrients of the whole soybeans were calculated in the usual indirect manner. During this period the soybeans were fed first and the sheep invariably ate their allotment of beans completely before the straw was given. Hence in making the calculations it is considered that the nutrients found in the orts from this period originated from the straw alone.

TABLE 2.—AVERAGE PERCENTAGE COMPOSITION AND GROSS ENERGY CONTENT OF FEEDS AND RATIONS OFFERED, OF ORTS, OF RATIONS CONSUMED, AND OF FECES EXCRETED: INVESTIGATION OF 1923

	Dry matter	Crude protein	N-free extract	Ether extract	Ash	Crude fiber	Gross energy per kg.
Period I—Soybean hay, 1,051 grams							
	pct.	*pct.*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*
Soybean hay	88.2	14.8	34.9	3.53	8.23	26.8	3.82
Orts	75.5	5.85	28.3	.92	4.46	36.0	3.25
Ration consumed	90.9	16.7	36.3	4.05	....	25.2	3.95
Feces	47.4	5.84	14.8	1.68	6.54	18.5	2.09
Period II—Soybean straw, 1,135 grams							
Soybean straw	86.0	4.11	37.2	1.06	4.43	39.2	3.73
Orts	79.6	3.11	30.1	.78	3.09	41.6	3.39
Ration consumed	89.9	4.61	40.8	1.20	....	37.9	3.90
Feces	49.7	3.65	17.5	.96	3.71	23.9	2.23
Period III—Oat straw, 779 grams, and whole soybeans, 228 grams							
Oat straw	92.4	4.93	44.4	2.34	8.52	32.2	3.95
Whole soybeans	88.4	38.9	21.9	16.2	4.62	6.69	4.63
Ration offered	91.5	12.8	39.1	5.51	....	26.3	4.11
Orts	92.9	4.45	41.9	1.83	7.27	37.5	3.98
Ration consumed	91.3	14.5	38.8	6.32	....	24.1	4.15
Feces	51.9	4.52	24.2	2.35	6.03	14.8	2.28
Period IV—Oat straw, 900 grams							
Oat straw	94.4	4.67	42.3	1.76	8.45	37.2	4.05
Orts	93.6	3.88	42.4	1.45	7.30	38.7	4.03
Ration consumed	94.8	4.92	42.3	1.85	....	36.8	4.06
Feces	52.3	4.49	23.7	1.43	6.60	16.1	2.31
Period V—Soybean straw, 910 grams, and soybean oil meal, 225 grams							
Soybean straw	91.8	3.86	40.7	1.00	5.51	40.8	3.81
Soybean oil meal	88.7	38.8	32.6	4.69	6.53	6.08	4.29
Ration offered	91.3	10.8	39.0	1.73	....	34.0	3.91
Orts	92.4	4.60	36.8	.91	4.72	45.4	4.04
Ration consumed	92.7	11.7	39.2	1.80	....	33.2	3.90
Feces	45.7	3.91	15.9	.82	3.61	21.4	2.03

Similarly, the coefficients of digestibility of the nutrients of soybean oil meal were computed from the data obtained on the ration of soybean oil meal and soybean straw (Period V) and on the ration of soybean straw alone (Period II). In this period the soybean oil meal was sprinkled over the soybean straw in an attempt to induce a greater consumption of straw. This procedure did not obviate the

TABLE 3.—SUMMARY OF DIGESTION COEFFICIENTS OF RATIONS CONSUMED: INVESTIGATION OF 1923

Sheep No.	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
Period I—Soybean hay, 1,051 grams					
130	52	69	62	67	33
131	56	69	67	69	34
132	58	73	65	63	41
133	56	68	65	51	42
134	52	65	64	39	36
135	55	70	67	52	35
137	49	64	62	63	33
138	55	69	66	63	39
139	54	68	67	69	33
136	53	70	63	67	24
140	54	70	61	69	32
141	56	73	61	71	35
Average	54.1	69.0	64.1	61.9	34.7
Period II—Soybean straw, 1,135 grams					
130	41	9	48	−4	43
131	42	−7	52	15	43
132	39	18	44	12	41
133	41	26	58	14	25
134	42	16	55	47	33
135	45	30	61	25	30
136	36	12	51	3	27
137	41	20	56	13	30
138	40	11	54	21	32
139	40	10	54	3	31
140	38	5	56	0	26
141	40	24	57	26	21
Average	40.4	14.5	53.8	14.6	31.8
Period III—Oat straw, 779 grams, and whole soybeans, 228 grams					
130	46	66	48	63	38
131	47	70	46	67	40
132	45	63	46	64	35
133	47	69	37	63	49
134	42	69	28	70	42
135	47	73	40	58	41
136	46	73	41	72	38
137	48	72	45	59	42
138	49	76	41	65	40
139	51	73	44	63	50
140	54	74	50	77	48
141	53	73	46	79	51
Average	47.9	70.9	42.7	66.7	42.8

TABLE 3.—*Concluded*

Sheep No.	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
Period IV—Oat straw, 900 grams					
130	36	47	34	11	49
131	43	18	35	26	60
132	41	19	41	32	50
133	48	14	49	31	56
134	48	11	45	34	61
135	49	25	48	35	56
136	53	−3	53	26	65
137	50	−6	46	21	68
138	56	10	54	37	67
139	45	17	45	15	55
140	39	13	42	9	47
141	46	6	49	3	53
Average	46.2	14.3	45.1	23.3	57.3
Period V—Soybean straw, 910 grams, and soybean oil meal, 225 grams					
130	53	66	63	51	38
131	54	68	60	57	43
132	56	70	61	60	46
133	55	69	65	71	41
134	54	66	66	42	40
135	55	68	69	47	36
136	57	66	67	63	44
137	59	70	71	46	46
138	59	69	66	69	50
139	52	68	58	68	41
140	55	70	61	70	44
141	56	70	62	65	46
Average	55.4	68.3	64.1	59.1	42.9

possibility that the nutrients in the orts were derived both from the soybean oil meal and from the soybean straw, but from the similarity in appearance of the orts to the coarser portions of the straw, and also from the similarity in composition, it is assumed that all of the nutrients in the orts are derived from the straw. The individual coefficients of digestibility obtained from the data on each sheep and the averages for whole soybeans and for soybean oil meal are given in Table 4.

Metabolizable Energy of Soybean Products.—The metabolizable energy of each ration and of each feed was calculated in the usual manner, i.e., by subtracting from the gross energy of the feed consumed the gross energy of the solid, liquid (corrected to nitrogen equilibrium), and gaseous excreta. The gross energy of the feeds and of the solid and liquid excreta was determined directly in a calorimetric bomb. It may safely be assumed that all of the energy lost in the gaseous excreta of ruminants is in the methane produced by the fermentation of carbohydrates. According to Armsby[26*] steers produce 4.5 grams of methane for each 100 grams of digestible car-

TABLE 4.—SUMMARY OF DIGESTION COEFFICIENTS OF WHOLE SOYBEANS AND OF SOYBEAN OIL MEAL, CALCULATED INDIRECTLY FROM PERIODS III AND V: INVESTIGATION OF 1923

Sheep No.	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
			Period III—Whole Soybeans		
130	48	85	68	82	−247
131	51	88	54	86	−215
132	40	82	53	83	−307
133	49	90	−16[a]	81	− 58
134	32	84	−62[a]	87	−113
135	49	89	17	70	− 88
136	47	94	20	92	−166
137	52	92	43	73	−110
138	54	97	26	81	−101
139	63	94	39	77	− 40
140	75	94	74	96	− 61
141	74	93	53	100	− 33
Average	52.8	90.1	44.7	84.0	−128.3
			Period V—Soybean oil meal		
130	102	86	109	80	178
131	107	88	90	92	323
132	110	89	94	92	326
133	115	89	124	118	258
134	111	85	126	64	247
135	110	87	137	72	132
136	120	81	127	97	393
137	132	86	149	67	436
138	130	84	124	107	534
139	101	92	77	117	285
140	109	93	89	120	333
141	121	96	96	112	431
Average	114.0	88.0	111.8	94.8	323.0

[a]Omitted from average.

bohydrates in the ration and each gram of methane has a calorific value of 13.34 calories. The energy lost in the gaseous excreta was calculated using these factors.

Unless the animal is neither gaining nor losing body protein, the difference between the energy consumed and the energy lost in the solid, liquid, and gaseous excreta does not indicate the true metabolizable energy value of the feed. A correction for the gain or loss of body protein was made according to the factor suggested by Rubner.[27*] For each gram of urinary nitrogen derived from the catabolism of body proteins (equal to negative nitrogen balance) 7.45 calories are subtracted from the urinary energy, and for each gram of nitrogen stored in the body (equal to the positive nitrogen balance) 7.45 calories are added to the urinary energy. The nitrogen balance of each animal in each period is given in the Appendix, Table 20.

The data concerning the gross energy, of feed and excreta, and the metabolizable energy of each of the rations fed during the five periods,

TABLE 5.—THE GROSS ENERGY, ITS LOSSES, ITS PERCENTAGE DISTRIBUTION, AND THE METABOLIZABLE ENERGY OF THE RATIONS FED: INVESTIGATION OF 1923

Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Percentage losses			Metabolizable	Metabolizable energy	
			Total	Losses			Metabolizable						
	Coarse feed	Concentrates		In feces	In urine	In methane		In feces	In urine	In methan		Per kg. digestible organic matter	Per kg. total digestible nutrients
Period I—Soybean hay													
	kg.	*kg.*	*therms*	*therms*	*therms*	*therms*	*therms*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*	*therms*
130....	.801	None	4.326	2.048	.216	.200	1.862	47.34	4.99	4.62	43.04	3.79	3.51
131....	.732	None	4.324	1.857	.234	.209	2.024	42.95	5.41	4.83	46.81	3.93	3.63
132....	.691	None	4.357	1.814	.242	.217	2.084	41.63	5.55	4.98	47.83	3.70	3.64
133....	.761	None	4.330	1.884	.208	.242	1.996	43.51	4.80	5.59	46.10	3.71	3.59
134....	.861	None	4.319	2.102	.149	.227	1.841	48.67	3.45	5.26	42.63	3.96	3.60
135....	.735	None	4.324	1.888	.210	.235	1.991	43.66	4.86	5.43	46.05	3.73	3.60
137....	.862	None	4.533	2.244	.201	.192	1.896	49.50	4.43	4.24	41.83	3.88	3.61
138....	.716	None	4.543	1.958	.226	.224	2.135	43.10	4.97	4.93	47.00	4.00	3.71
139....	.817	None	4.556	2.120	.213	.222	2.001	46.53	4.68	4.87	43.92	3.83	3.55
136....	.810	None	4.134	2.253	.196	.175	1.510	54.50	4.74	4.23	36.53	3.29	3.00
140....	.881	None	4.145	2.181	.219	.186	1.559	52.62	5.28	4.49	37.61	3.30	3.02
141....	.872	None	4.148	1.932	.228	.192	1.796	46.58	5.50	4.63	43.30	3.68	3.36
Average	.795	None	4.333	2.033	.196	.208	1.896	46.92	4.52	4.80	43.76	3.73	3.49
Period II—Soybean straw													
130....	.639	None	5.034	2.551	.020	.241	2.222	50.68	.40	4.79	44.14	5.46	5.46
131....	.596	None	4.372	2.619	.019	.252	1.482	59.90	.43	5.76	33.90	3.54	3.53
132....	.517	None	4.346	2.621	.028	.227	1.470	60.31	.64	5.22	33.82	3.80	3.79
133....	.737	None	4.419	2.643	.058	.223	1.495	59.81	.31	5.05	33.83	3.85	3.83
134....	.792	None	4.336	2.631	.045	.240	1.420	60.67	.38	5.53	32.75	3.49	3.42
135....	.628	None	4.343	2.440	.064	.243	1.596	56.18	.47	5.60	36.75	3.73	3.69
136....	.718	None	4.202	2.780	.048	.205	1.169	66.16	1.42	4.88	27.82	3.36	3.35
137....	.755	None	4.156	2.707	.057	.229	1.163	65.13	1.37	5.51	27.98	2.95	2.94
138....	.619	None	4.164	2.964	.051	.226	.923	71.18	1.22	5.43	22.17	2.39	2.36
139....	.750	None	4.309	2.687	.032	.230	1.360	62.36	.74	5.34	31.56	3.49	3.49
140....	.716	None	4.331	2.786	.040	.221	1.283	64.33	.92	5.10	29.62	3.47	3.47
141....	.616	None	4.164	2.651	.046	.216	1.251	63.66	1.10	5.19	30.04	3.34	3.29
Average	.674	None	4.345	2.676	.042	.229	1.398	61.59	.97	5.27	32.17	3.57	3.55

TABLE 5.—*Continued*

Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Percentage losses			Metabolizable	Metabolizable energy	
			Total	Losses			Metabolizable						
	Coarse feed	Concentrates		In feces	In urine	In methane		In feces	In urine	In methane		Per kg. digestible organic matter	Per kg. total digestible nutrients
Period III—Oat straw and whole soybeans													
	kg.	*kg.*	*therms*	*therms*	*therms*	*therms*	*therms*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*	*therms*
130	.649	.197	4.379	2.654	.167	.194	1.364	60.61	3.81	4.43	31.15	3.02	2.06
131	.642	.197	4.390	2.511	.126	.193	1.560	57.20	2.87	4.40	35.54	3.42	3.10
132	.693	.197	4.384	2.610	.185	.186	1.403	59.53	4.22	4.24	32.00	3.25	2.95
133	.684	.199	4.576	2.199	.183	.176	2.018	48.05	4.00	3.85	44.10	4.72	4.26
134	.535	.199	4.643	2.316	.144	.138	2.045	49.88	3.10	2.97	44.04	5.35	4.64
135	.440	.199	4.734	1.709	.136	.154	2.735	36.10	2.87	3.25	57.77	6.35	5.64
136	.509	.203	4.663	2.565	.168	.160	1.770	55.00	3.60	3.43	37.96	3.96	3.43
137	.475	.203	4.695	2.474	.192	.175	1.854	52.69	4.09	3.73	39.49	4.00	3.55
138	.421	.203	4.709	2.195	.195	.158	2.161	46.61	4.14	3.36	45.89	4.67	4.06
139	.546	.205	4.447	2.319	.217	.190	1.721	52.15	4.88	4.27	38.70	3.57	3.19
140	.539	.205	4.438	2.075	.148	.202	2.013	46.76	3.33	4.55	45.36	3.94	3.46
141	.558	.205	4.447	2.000	.276	.201	1.970	44.97	6.21	4.52	44.30	3.89	3.41
Average	.558	.201	4.616	2.361	.182	.182	1.891	51.15	3.94	3.94	40.97	4.18	3.65
Period IV—Oat straw													
130	.627	None	4.251	2.747	.073	.200	1.231	64.62	.72	4.70	28.96	3.63	3.59
131	.737	None	4.269	2.510	.072	.233	1.454	58.80	.69	5.46	34.06	3.62	3.56
132	.760	None	4.261	2.603	.062	.224	1.372	61.09	.46	5.26	32.20	3.51	3.42
133	.749	None	4.116	2.311	.094	.258	1.453	56.15	2.28	6.27	35.30	3.29	3.23
134	.756	None	4.123	2.202	.087	.259	1.575	53.41	2.11	6.28	38.20	3.53	3.46
135	.509	None	4.037	2.295	.112	.250	1.380	56.85	2.77	6.19	34.18	3.14	3.07
136	.677	None	4.386	2.114	.078	.306	1.888	48.20	1.78	6.98	43.04	3.68	3.64
137	.626	None	4.381	2.247	.107	.292	1.735	51.29	2.44	6.67	39.60	3.56	3.53
138	.643	None	4.402	2.020	.067	.313	2.002	45.89	1.52	7.11	45.48	3.74	3.69
139	.664	None	4.385	2.422	.058	.252	1.653	55.23	1.32	5.75	37.70	3.83	3.80
140	.594	None	4.409	2.611	.099	.219	1.480	59.22	2.25	4.97	33.57	3.95	3.93
141	.594	None	4.409	2.406	.058	.260	1.685	54.57	1.32	5.90	38.22	3.88	3.88
Average	.661	None	4.283	2.374	.080	.255	1.574	55.43	1.87	5.95	36.75	3.61	3.57

TABLE 5.—*Concluded*

Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Percentage losses			Metabolizable	Metabolizable energy	
			Total	Losses			Metabolizable						
	Coarse feed	Concentrates		In feces	In urine	In methane		In feces	In urine	In methane		Per kg. digestible organic matter	Per kg. total digestible nutrients
Period V—Soybean straw and soybean oil meal													
	kg.	*kg*	*therms*	*therms*	*therms*	*therms*	*therms*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*	*therms*
130....	.786	.200	4 290	2.114	.104	.248	1.824	49.28	2.42	5.78	42.52	3.95	3.84
131....	.810	.200	4.284	2.088	.093	.252	1.851	48.74	2.17	5.88	43.21	3.62	3.52
132....	.700	.200	4.276	1.967	.092	.256	1.961	46.00	2.15	5.99	45.86	3.69	3.59
133....	.807	.200	4.280	2.178	.142	.261	1.699	50.89	3.32	6.10	39.70	3.20	3.10
134....	.804	.200	4.287	2.046	.139	.260	1.842	47.73	3.24	6.06	42.97	3.53	3.47
135....	.734	.200	4.278	2.044	.150	.255	1.829	47.78	3.51	5.96	42.75	3.50	3.42
136....	.779	.198	4.399	1.975	.129	.273	2.022	44.90	2.93	6.21	45.96	3.73	3.63
137....	.770	.198	4.401	1.789	.136	.286	2.190	40.65	3.09	6.50	49.76	3.86	3.79
138....	.765	.198	4.404	1.642	.122	.283	2.357	37.28	2.77	6.43	53.52	4.16	4.05
139....	.817	.199	4.162	2.018	.131	.233	1.780	48.49	3.15	5.60	42.77	3.66	3.53
140....	.743	.199	4.138	1.917	.132	.244	1.845	46.33	3.19	5.90	44.59	3.61	3.48
141....	.811	.199	4.160	1.857	.107	.253	1.943	44.64	2.57	6.08	46.71	3.71	3.60
Average	.777	.199	4.278	1.972	.123	.259	1.924	46.11	2.88	6.04	44.97	3.69	3.59

are tabulated in Table 5. The metabolizable energy of each ration is expressed in therms per kilogram of dry matter and per kilogram of digestible organic matter, according to the method followed by Armsby, and also per kilogram of total digestible nutrients, in the calculation of which allowance is made for the superior energy content of fat.

The metabolizable energy of the whole soybeans and of the soybean oil meal is calculated by an indirect method exactly analogous to the indirect method for the calculation of the coefficients of digestibility of these concentrates. The calculated metabolizable energy content of these two concentrates for each sheep is given in Table 6 and the average metabolizable energy of each ration and each feed alone is given in Table 7.

TABLE 6.—METABOLIZABLE ENERGY OF WHOLE SOYBEANS AND OF SOYBEAN OIL MEAL[a]: INVESTIGATION OF 1923

Sheep No.	Whole soybeans (fed with oat straw)			Soybean oil meal (fed with soybean straw)		
	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients[b]	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients[b]
	therms	*therms*	*therms*	*therms*	*therms*	*therms*
130	.70	1.36	1.02	3.44	3.67	3.47
131	1.52	2.88	2.14	3.65	3.69	3.48
132	.82	1.92	1.36	3.88	3.85	3.63
133	3.73	8.17	5.84	2.91	2.68	2.50
134	3.44	12.28[c]	7.22[c]	3.61	3.48	3.34
135	5.51[c]	11.38[c]	8.59[c]	3.44	3.40	3.25
136	2.37	4.59	3.21	4.47	3.94	3.73
137	2.61	4.60	3.52	5.26[c]	4.20	4.06
138	3.51	6.19	4.61	6.04[c]	4.89[c]	4.63[c]
139	2.16	3.46	2.65	3.59	3.79	3.50
140	3.23	4.40	3.33	3.75	3.65	3.39
141	3.05	4.32	3.21	4.40	3.90	3.66
Aver. (all)	2.47	4.19	3.09	3.71	3.66	3.46
Aver. last 6 sheep	2.82	4.60	3.42	....	....	....

[a]The metabolizable energy of the roughage in the ration is calculated by multiplying the kilograms of total digestible nutrients in the roughage consumed, by the average therms of metabolizable energy per kilogram of total digestible nutrients in that roughage as found in a previous trial on the roughage alone, namely, Period IV for oat straw and Period II for soybean straw.

[b]Total digestible nutrients are equal to the sum of digestible crude protein, digestible carbohydrates, and 2.25 times digestible ether extract.

[c]These values are higher than the values for corresponding gross energy per unit of weight indicated and are therefore omitted from the averages.

Discussion.—The digestion coefficients obtained for each ration are fairly concordant, as may be seen by reference to Table 3. The variations among individual coefficients are, in general, small for those nutrients present in the ration in considerable concentration. As was to be expected, considerable variations were obtained with reference to the nutrients present in only small amounts. This is especially noticeable in case of the protein and ether extract of soybean straw and of oat straw; the soybean straw contained but 4.0 percent of protein and

TABLE 7.—SUMMARY OF AVERAGE METABOLIZABLE ENERGY VALUES OF THE FEEDS AND RATIONS FED: INVESTIGATION OF 1923

Feed or ration	Number averaged	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients
		therms	*therms*	*therms*
Soybean hay, 1,051 grams	12	1.90	3.73	3.49
Soybean straw, 1,135 grams	12	1.40	3.57	3.55
Oat straw, 779 grams, and whole soybeans, 228 grams	12	1.89	4.18	3.65
Oat straw, 900 grams	12	1.57	3.61	3.57
Soybean straw, 910 grams, and soybean oil meal, 225 grams	12	1.92	3.69	3.59
Whole soybeans, 228 grams (fed with oat straw, 779 grams)	6	2.82	4.60	3.42
Soybean oil meal, 225 grams (fed with soybean straw, 910 grams)	12	3.71	3.66	3.46

1.0 percent of fat and the oat straw 4.8 percent of protein and 2.1 percent of fat.

While, in general, fairly concordant results were obtained for the digestion coefficients of the rations as fed, quite the opposite was the case when coefficients of digestibility of whole soybeans and of soybean oil meal were calculated in the usual indirect manner, as may be seen from Table 4. The digestion coefficients computed for whole soybeans vary for dry substance from 32 to 75; for crude protein, from 82 to 97; for nitrogen-free extract, from —62 to 74; for ether extract, from 70 to 100; and for crude fiber, from —307 to —33. For soybean oil meal, the digestion coefficients vary for dry substance from 101 to 132; for crude protein from 81 to 96; for nitrogen-free extract, from 77 to 149; for ether extract, from 64 to 120; and for crude fiber, from 132 to 534. These variable and frequently impossible results indicate that the assumptions upon which the indirect method of calculation is based are in considerable error.

Variations in the coefficients obtained in a digestion trial are due chiefly to three causes: variations in the digestive capacity of the animal, variations in the character of the feed, and technical errors of the test itself. The technical errors of the test may be due to avoidable causes, such as errors in the taking of weights or in the analysis of feeds and excreta, or to unavoidable causes, such as irregularities in the voiding of excreta, the presence of metabolic products in the feces, and a variable consumption of feed by the experimental animals.

In this investigation variations in results due to variable performance of the animals were reduced to a minimum by the use of 12 experimental animals. There should be only inconsiderable variations traceable to the character of the feeds, since the total supply of each kind was obtained at the same time, from the same place. As to variations caused by technical errors, the effect of irregular excretion was probably not large, since a collection period of 7 days, following a 10-day preliminary period, was used thruout. There is no apparent reason

for suspecting the accuracy of the weights and the chemical analyses obtained. There remain, therefore, two possible sources of error, caused by the presence of metabolic products in the feces and by the irregular consumption of the experimental rations. The former error is inherent in all digestion trials and is unavoidable until some satisfactory method is devised for the separation of food residues from so-called metabolic products in the feces. The effect of these products upon the coefficients of digestibility computed by the ordinary method is to underestimate the true digestibility.

Probably the most serious source of error in this experiment was the rather large percentage of refused feed in practically every period. Of the total dry substance offered, the following average percentages were refused: soybean hay 13.9 percent, soybean straw 31.1 percent, oat straw and whole soybeans 22.3 percent, oat straw alone 22.2 percent, and soybean straw and soybean oil meal 6.9 percent.

The partial refusal of feed by experimental animals is unavoidable in so far as it is due to the inherent character of the feed rather than to mere fickleness in the appetites of the animals or to the use of inferior samples of feed. It is unfortunately true that soybean roughages of good grade are rarely consumed completely when offered to farm animals, because of the woody stems always present. The samples of roughages used in this experiment were of this character and it is questionable whether a repetition of the experiment on the roughages alone would have given any more satisfactory results. A study of Table 2 shows that the feed consumed did not differ markedly in composition from the feed offered, but nevertheless the use of the digestion coefficients in connection with weights of roughages offered to animals would give an exaggerated estimate of the digestible nutrients consumed. In so far as the orts are actually inedible, the nutrients contained in them are in the same category, for all practical purposes, as the nutrients contained in the feces.

With the soybean concentrates, the case is different. The variable and frequently impossible coefficients calculated indirectly for these feeds in the foregoing experiments evidently are of no practical significance. Digestion experiments were therefore again undertaken with whole soybeans and soybean oil meal in 1925, using alfalfa hay as the basal ration, instead of the less palatable oat straw and soybean roughages.

INVESTIGATION OF 1925

Plan of Investigation

The 1925 investigation was concerned with the redetermination of the digestibility and metabolizable energy of whole soybeans and of soybean oil meal. Six sheep were used thruout this part of the investigation and the collection periods were lengthened from 7 to 10 days.

The rations and their order of sequence were as follows: in Period VI, 800 grams of alfalfa hay; in Period VII, 800 grams of alfalfa hay and 225 grams of whole soybeans; in Period VIII, 800 grams of alfalfa hay and 112 grams of soybean oil meal; in Period IX, 800 grams of alfalfa hay and 340 grams of soybean oil meal; and in Period X, 450 grams of soybean oil meal alone. Each sheep received 10 grams of salt daily. With the exception of Period X, data were collected for each period with each of the six sheep. In Period X, only Sheep R3 consumed the 450 grams of soybean oil meal daily for the necessary 20 days. An attempt was made also to feed whole soybeans alone, but this was unsuccessful, due to the scouring effect after the first few days on this ration.

Considering alfalfa hay as the basal ration, the digestibility and the metabolizable energy of the whole soybeans and of the soybean oil meal, the latter at two different levels, were calculated in the usual indirect manner. Considering 800 grams of alfalfa hay and 112 grams of soybean oil meal, the ration fed in Period VIII, as the basal ration in Period IX, the digestibility and the metabolizable energy of the additional 228 grams of soybean oil meal fed in the latter period was computed. This was done with the thought that any associative effects of combining soybean oil meal with alfalfa might be partially or wholly overcome by the 112 grams of soybean oil meal, and therefore the computed digestibility of the nutrients and the metabolizable energy of the additional 228 grams might be more nearly representative of the true values of this concentrate when fed alone. Finally, these values obtained by the indirect method were compared with those directly obtained for one sheep when the concentrate was fed alone in Period X.

The digestion trials of the 1925 investigation were managed in a manner very similar to those of the 1923 investigation. The errors incurred in the latter investigation by the comparatively large amounts of refused feeds were completely obviated in the second investigation by feeding such amounts of a very palatable feed as would be readily consumed and at the same time would adequately cover the maintenance requirements of the sheep. All sheep either maintained their weights or gained slightly during each trial and with one exception (Sheep R3 in Period VIII had a negative nitrogen balance of .15 gram daily) all sheep were in positive nitrogen balance in all periods. There was not more than a handful of refused feed from any one sheep at the end of any period.

The sheep used in this part of the investigation were Western yearling wethers varying in weight from 80 to 110 pounds, and were again run in groups of three. Two changes were made in each of the metabolism crates during this year. The cloth on the lower screen for recovering the feces was replaced by copper screening permanently

attached to a metal frame, and windows were placed on both sides of the crate instead of on one only, thus permitting the sheep to see sheep in adjoining crates. Both windows were fitted with ¼-inch iron bars placed vertically 3 inches apart. After a year's use of the modified crates, the authors were satisfied that the changes were well worth while.

Experimental Results Obtained in 1925

Digestibility.—The calculation of the coefficients of digestibility of the nutrients in each of the five rations fed was made in the usual direct manner and, considering the alfalfa hay as the basal ration in Periods VII, VIII, and IX, the digestion coefficients of the nutrients in whole soybeans and in soybean oil meal, the latter at the two different levels, were calculated according to the usual indirect fashion. Considering the 800 grams of alfalfa hay and the 112 grams of soybean oil meal, the ration fed in Period VIII, as the basal ration in Period IX,

TABLE 8.—AVERAGE PERCENTAGE COMPOSITION AND GROSS ENERGY CONTENT OF FEEDS AND RATIONS CONSUMED AND OF FECES EXCRETED: INVESTIGATION OF 1925

	Dry matter	Crude protein	N-free extract	Ether extract	Ash	Crude fiber	Gross energy per kg.
Period VI—Alfalfa hay, 800 grams							
	pct.	*pct.*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*
Alfalfa hay	94.4	19.4	35.8	2.76	9.55	26.9	4.24
Feces	71.8	9.28	19.0	3.83	10.2	30.4	3.20
Period VII—Alfalfa hay, 800 grams, and whole soybeans, 225 grams							
Alfalfa hay	95.5	20.8	36.1	2.66	10.4	25.5	4.19
Soybeans	94.0	32.6	29.1	19.5	5.94	6.90	5.21
Ration consumed	95.5	23.0	34.5	6.35	.....	21.0	4.42
Feces	69.2	10.3	19.2	3.03	9.51	27.22	3.19
Period VIII—Alfalfa hay, 800 grams, and soybean oil meal, 112 grams							
Alfalfa hay[a]	91.0	19.0	36.3	2.58	9.36	23.8	4.02
Soybean oil meal	90.7	38.8	30.5	6.18	6.57	8.67	4.39
Ration consumed	91.0	22.7	35.5	3.23	.....	21.0	4.07
Feces	71.4	10.5	18.5	2.96	10.7	28.8	3.08
Period IX—Alfalfa hay, 800 grams, and soybean oil meal, 340 grams							
Alfalfa hay	87.5	14.3	34.7	1.71	7.49	29.4	3.84
Soybean oil meal	91.2	40.4	31.1	5.04	6.48	8.16	4.35
Rations consumed	93.0	23.3	34.8	2.80	.....	23.0	3.95
Feces	60.0	9.39	14.2	1.59	7.22	27.6	2.69
Period X—Soybean oil meal, 450 grams							
Soybean oil meal	89.6	39.2	30.3	5.20	6.38	8.51	4.28
Feces	45.1	9.66	13.8	3.22	8.37	10.0	2.21

[a]The chemical analyses of the alfalfa hay fed to the two groups of sheep in this period were: for sheep B1, B2, and B3, dry substance 91.47 percent, crude protein 24.06, N-free extract 36.01, crude fiber 17.68, ether extract 3.34, ash 10.38, and gross energy 4,066 calories per gram; for sheep R1, R2, and R3, dry substance 90.90 percent, crude protein 16.53 percent, N-free extract 36.4, crude fiber 26.79, ether extract 2.20, ash 8.86, and gross energy 3,995 calories per gram.

the digestibility of the nutrients in the additional 228 grams of soybean oil meal fed in this period was also calculated. A direct determination of the digestion coefficients of soybean oil meal was obtained in Period X, in which one sheep ate soybean oil meal alone.

The average percentage composition and the gross energy content of the feeds and rations consumed and of the feces of each period are tabulated in Table 8. The digestion coefficients of each ration and each feed, obtained directly or calculated by current methods, are given in Table 9.

TABLE 9.—SUMMARY OF DIGESTION COEFFICIENTS: INVESTIGATION OF 1925

Sheep No.	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
Period VI—Alfalfa hay, 800 grams					
B1	66	78	77	63	48
B2	66	80	77	63	48
B3	66	81	77	58	48
R1	63	76	74	45	47
R2	65	78	75	40	51
R3	63	77	75	34	48
Average	65	78	76	51	48
Period VII—Alfalfa hay, 800 grams, and whole soybeans, 225 grams					
B1	69	80	78	78	55
B2	70	82	76	81	51
B3	69	81	75	78	51
R1	67	80	76	80	37
R2	69	81	76	80	39
R3	72	83	79	84	46
Average	69	81	77	80	47
Period VIII—Alfalfa hay, 800 grams, and soybean oil meal, 112 grams					
B1	67	82	78	67	28
B2	66	83	76	55	27
B3	68	83	78	64	29
R1	63	73	76	44	48
R2	61	73	76	50	42
R3	58	74	73	48	37
Average	64	78	76	55	35
Period IX—Alfalfa hay, 800 grams, and soybean oil meal, 340 grams					
B1	67	80	80	67	41
B2	67	80	79	71	41
B3	67	80	79	67	42
R1	65	75	78	63	43
R2	62	77	77	75	30
R3	64	79	77	78	37
Average	65	78	78	70	39
Period X—Soybean oil meal alone, 450 grams					
R3	81	90	82	74	55

TABLE 9.—*Concluded*

Sheep No.	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
Period VII—Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams)[a]					
B1	84	82	86	89	88
B2	87	89	77	93	94
B3	84	88	74	89	88
R1	75	85	79	95	−90
R2	80	90	79	95	−77
R3	94	95	94	102	10
Average	84	88	82	94	19
Period VIII—Soybean oil meal, 112 grams (fed with alfalfa hay, 800 grams)[a]					
B1	80	98	97	100	−270
B2	73	104	76	100	−280
B3	86	107	103	90	−250
R1	49	55	76	17	0
R2	36	59	81	50	− 90
R3	10	57	53	24	−230
Average	56	80	81	64	−187
Period IX—Soybean oil meal, 340 grams (fed with alfalfa hay, 800 grams)[a]					
B1	73	82	91	76	− 21
B2	72	81	89	88	− 14
B3	72	82	87	76	− 11
R1	64	72	84	72	0
R2	53	77	81	88	−168
R3	62	80	81	94	− 88
Average	66	79	86	82	− 50
Period IX—Soybean oil meal, 228 grams (fed with alfalfa hay, 800 grams, and soybean oil meal, 112 grams)[a]					
B1	74	84	94	91	116
B2	73	82	92	100	116
B3	72	85	92	81	127
R1	62	71	86	75	135
R2	44	76	81	109	− 47
R3	57	80	81	119	71
Average	64	80	88	96	86

[a]Indirectly determined.

Metabolizable Energy.—As in the first investigation sufficient data were obtained for each sheep and each ration for the satisfactory calculation of metabolizable energy. The nitrogen balance data are tabulated in the Appendix, Table 21, while Table 10 presents the intermediate and final calculations of metabolizable energy. Table 11 gives the indirectly calculated values for the metabolizable energy of whole soybeans and of soybean oil meal. Table 12 presents a summary of the metabolizable energy of all feeds and rations fed in the investigation of 1925.

Discussion.—In general, the 1925 trials were quite satisfactory. The coefficients of digestibility of the nutrients and the metabolizable

TABLE 10.—THE GROSS ENERGY, ITS LOSSES, ITS PERCENTAGE DISTRIBUTION AND THE METABOLIZABLE ENERGY OF THE RATIONS FED: INVESTIGATION OF 1925

Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Percentage losses			Metabolizable	Metabolizable energy	
			Total	Losses			Metabolizable					Per kg. digestible organic matter	Per kg. total digestible nutrients
	Coarse feed	Concentrates		In feces	In urine	In methane		In feces	In urine	In methane			
			Period VI—Alfalfa hay, 800 grams										
	kg.	*kg.*	*therms*	*therms*	*therms*	*therms*	*therms*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*	*therms*
B1.....	.753	....	4.507	1.509	.219	.251	2.528	33.48	4.86	5.57	56.09	4.204	4.034
B2.....	.753	....	4.507	1.488	.300	.248	2.471	33.01	6.66	5.50	54.83	4.099	3.934
B3.....	.753	....	4.507	1.505	.305	.248	2.449	33.39	6.77	5.50	54.34	4.053	3.899
R1.....	.757	....	4.483	1.649	.197	.255	2.382	36.78	4.39	5.69	53.14	4.054	3.956
R2.....	.757	....	4.483	1.572	.269	.263	2.409	35.07	5.33	5.86	53.74	3.924	3.840
R3.....	.473	....	4.483	1.607	.226	.257	2.393	35.84	5.04	5.73	53.39	4.043	3.972
Average	.708	....	4.495	1.555	.248	.254	2.438	34.59	5.51	5.64	54.26	4.063	3.939
			Period VII—Alfalfa hay, 800 grams, and whole soybeans, 225 grams										
B1.....	.770	.212	4.662	1.412	.218	.242	2.790	30.29	4.68	5.19	59.84	4.361	3.970
B2.....	.770	.212	4.662	1.385	.237	.239	2.801	29.71	5.08	5.13	60.08	4.358	3.963
B3.....	.770	.212	4.662	1.427	.263	.237	2.735	30.61	5.64	5.08	58.67	4.304	3.921
R1.....	.758	.212	4.609	1.529	.229	.213	2.638	33.17	4.97	4.62	57.24	4.272	3.842
R2.....	.758	.212	4.609	1.462	.231	.216	2.700	31.72	5.01	4.69	58.58	4.315	3.886
R3.....	.758	.212	4.609	1.264	.265	.231	2.849	27.42	5.75	5.01	61.82	4.346	3.909
Average	.764	.212	4.636	1.413	.241	.230	2.752	30.49	5.20	4.95	59.37	4.326	3.915

TABLE 10.—*Concluded*

Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Percentage losses			Metabolizable	Metabolizable energy	
			Total	Losses			Metabolizable					Per kg. digestible organic matter	Per kg. total digestible nutrients
	Coarse feed	Concentrates		In feces	In urine	In methane		In feces	In urine	In methane			
Period VIII—Alfalfa hay, 800 grams, and soybean oil meal, 112 grams													
	kg.	*kg.*	*therms*	*therms*	*therms*	*therms*	*therms*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*	*therms*
B1.....	.732	.101	4.509	1.430	.211	.211	2.657	31.71	4.68	4.68	58.93	4.271	4.033
B2.....	.732	.101	4.509	1.485	.220	.204	2.600	32.93	4.88	4.52	57.67	4.224	3.987
B3.....	.732	.101	4.509	1.433	.230	.212	2.634	31.78	5.10	4.70	58.42	4.184	3.963
R1....	.726	.101	4.466	1.633	.148	.249	2.436	36.57	3.31	5.58	54.54	4.078	3.966
R2....	.727	.101	4.428	1.660	.173	.252	2.343	37.49	3.91	5.69	52.91	3.924	3.807
R3....	.727	.101	4.428	1.658	.168	.235	2.367	37.44	3.79	5.31	53.46	4.190	4.069
Average	.729	.101	4.475	1.550	.192	.227	2.506	34.66	4.29	5.08	55.97	4.145	3.971
Period IX—Alfalfa hay, 800 grams, and soybean oil meal, 340 grams													
B1.....	.679	.309	4.502	1.455	.236	.242	2.569	32.32	5.24	5.38	57.06	4.054	3.899
B2.....	.679	.309	4.502	1.482	.196	.241	2.583	32.92	4.35	5.35	57.38	4.090	3.925
B3.....	.679	.309	4.502	1.492	.255	.241	2.514	33.14	5.66	5.35	55.85	3.981	3.827
R1....	.727	.312	4.497	1.480	.250	.244	2.523	32.91	5.56	5.43	56.10	4.102	3.932
R2....	.695	.308	4.500	1.781	.209	.224	2.286	39.58	4.64	4.98	50.80	3.972	3.799
R3....	.695	.308	4.500	1.653	.244	.241	2.362	36.73	5.42	5.36	52.49	3.934	3.762
Average	.692	.309	4.501	1.557	.232	.239	2.473	34.60	5.15	5.31	54.94	4.023	3.857
Period X—Soybean oil meal, 450 grams													
R3....	....	.403	4.784	.938	.385	.199	3.492	19.61	8.05	4.16	68.18	4.215	3.937

TABLE 11.—COMPUTED METABOLIZABLE ENERGY OF WHOLE SOYBEANS AND OF SOYBEAN OIL MEAL: INVESTIGATION OF 1925

Sheep No.	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients
Period VII—Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams)			
	therms	*therms*	*therms*
B1	4.123	5.141	3.995
B2	4.174	5.145	3.964
B3	3.873	4.946	3.823
R1	3.292	4.950	3.607
R2	3.575	5.087	3.762
R3	4.259	5.073	3.856
Average	3.883	5.057	3.835
Period IX—Soybean oil meal, 228 grams (fed with soybean oil meal, 112 grams, and alfalfa hay, 800 grams)			
B1	3.266	3.841	3.586
B2	3.333	3.966	3.675
B3	3.005	3.555	3.317
R1	3.053	3.938	3.704
R2	2.126	3.318	2.959
R3	2.515	3.279	2.973
Average	2.883	3.650	3.369

TABLE 12.—COMPUTED SUMMARY OF THE METABOLIZABLE ENERGY VALUES OF THE FEEDS AND RATIONS FED: INVESTIGATION OF 1925

Feed or ration	Number averaged	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients
		therms	*therms*	*therms*
Alfalfa hay, 800 grams	6	2.44	4.06	3.94
Whole soybeans, 225 grams, and alfalfa hay, 800 grams	6	2.75	4.33	3.91
Soybean oil meal, 112 grams, and alfalfa hay, 800 grams	6	2.51	4.15	3.97
Soybean oil meal, 340 grams, and alfalfa hay, 800 grams	6	2.47	4.02	3.86
Soybean oil meal, 450 grams	1	3.49	4.22	3.94
Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams)	6	3.88	5.06	3.84
Soybean oil meal, 228 grams (fed with soybean oil meal, 112 grams, and alfalfa hay, 800 grams	6	2.88	3.65	3.37

energy values of each of the rations fed were quite generally consistent for all six sheep. While the indirectly calculated coefficients were, in general, better than those of the 1923 trials, they are still far from being completely concordant. In addition to being more consistent, the 1925 results represent more nearly the true values of the feeds as fed, since there was no appreciable amount of refused feed in any period.

A modification of the ordinary method of computing indirect coefficients of digestion was resorted to in Period IX, in which 800 grams of alfalfa and 340 grams of soybean oil meal were fed. Considering the 800 grams of alfalfa hay as a basal ration, the coefficients of digestion of the nutrients in the 340 grams of soybean oil meal were

calculated. Then by considering the ration fed in Period VIII (800 grams of alfalfa hay and 112 grams of soybean oil meal) as the basal in Period IX, the coefficients of digestibility of the nutrients in the additional 228 grams of soybean oil meal were calculated. These figures are more consistent than those in the former calculation.

An inadvertent occurrence in Period VIII explains the discrepancy existing between the coefficients obtained for the two groups of sheep. Sheep B1, B2, and B3 were fed, during both the preliminary feeding period and the collection period, alfalfa hay containing an excessive amount of leaves and dust, the remains of the large stack of alfalfa which had been used in the preceding periods.[a] This hay contained 24.06 percent of crude protein, which is about 5 percent higher than the hay fed in the other periods, and only 17.68 percent of crude fiber, nearly 10 percent lower. The alfalfa hay fed to Sheep R1, R2, and R3 in this period was the same as in the other periods.

GENERAL DISCUSSION OF EXPERIMENTAL RESULTS

The digestion coefficients of all feeds and rations fed during both investigations are compiled in Table 13. In order to compare these results with others heretofore published, the literature was searched for all digestion experiments in which soybean products were used. There are at least two well-known compilations of average digestion coefficients, one by Lindsey, Haskins, Smith, and Beals,[24*] published in 1919, and one by Henry and Morrison,[21*] revised to 1923. These compilations, however, give only the average coefficients obtained for different species of animals. Since digestion coefficients for all concentrate feeds are indirectly obtained in the case of ruminants, it is of importance to know the basal rations to which these concentrates were added in order to discover to what extent associative effects may have operated.

In 1900 Jordan and Hall[29*] of the Office of Experiment Stations, U. S. Department of Agriculture, published a compilation giving in detail the data on all American digestion experiments. This valuable summary has never been brought up to date. In 1925 Fraps[30*] made a compilation somewhat similar to that of Jordan and Hall, tho including less information concerning the experimental conditions of the individual trials.[b]

[a] This experiment continued for a longer time than was anticipated and it was necessary at this point to purchase more alfalfa hay.

[b] In this compilation by Fraps two mistakes in the digestion coefficients given for soybean oil meal were noted when the original data were consulted. In the second line of Table 8, page 55, of Fraps' bulletin, the averages of 77.2 for protein, 74.2 for ether extract, etc., for soybean meal, are the average coefficients for a ration of .5 pound of soybean meal and 1 pound of timothy rowen hay obtained by Phelps and Woods[8*] on sheep. In line three of the same table and page, the coefficients given are similar coefficients obtained by the same *(see page 266)*

TABLE 13.—SUMMARY OF DIGESTION COEFFICIENTS OF ALL FEEDS AND RATIONS FED IN BOTH INVESTIGATIONS

Period	Feed or ration	Single trials	Kinds	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
I	Soybean hay, 1,051 grams (1923)	12	1	54	69	64	62	35
II	Soybean straw, 1,135 grams (1923)	12	1	40	15	54	15	32
IV	Oat straw, 900 grams (1923)	12	1	46	8	45	23	57
VI	Alfalfa hay, 800 grams (1925)	6	1	65	78	76	51	48
III	Whole soybeans, 228 grams, and oat straw, 779 grams (1923)	12	1	48	71	43	67	43
VII	Whole soybeans, 225 grams, and alfalfa hay, 800 grams (1925)	6	1	69	81	77	80	47
V	Soybean oil meal, 225 grams, and soybean straw, 910 grams (1923)	12	1	55	68	64	59	43
VIII	Soybean oil meal, 112 grams, and alfalfa hay, 800 grams (1925)	6	1	64	78	76	55	35
IX	Soybean oil meal, 340 grams, and alfalfa hay, 800 grams (1925)	6	1	65	78	78	70	39
III	Whole soybeans, 228 grams (fed with oat straw, 779 grams) (1923)	12	1	53	90	45	84	−128
VII	Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams) (1925)	6	1	84	88	82	94	19
....	Whole soybeans, average	18	2	63	89	48	87	−79

TABLE 13—*Concluded*

Period	Feed or ration	Single trials	Kinds	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
V	Soybean oil meal, 225 grams (fed with soybean straw, 910 grams) (1923)	12	1	114	88	112	95	323
VIII	Soybean oil meal, 112 grams (fed with alfalfa hay, 800 grams) (1925)	6	1	56	80	81	64	−187
IX	Soybean oil meal, 340 grams (fed with alfalfa hay, 800 grams) (1925)[a]	6	1	66	79	86	82	−50
IX	Soybean oil meal, 228 grams (fed with soybean oil meal, 112 grams, and alfalfa hay, 800 grams) (1925)[a]	6	1	64	80	88	96	86
X	Soybean oil meal, 450 grams (alone)	1	1	81	90	82	74	55
....	Soybean oil meal, average[b]	25	2	87	84	98	87	133

[a]It should be noted that these two series of coefficients have been calculated from the same period, i.e., Period IX.
[b]In obtaining the average digestion coefficients for soybean oil meal, only one series of coefficients from Period IX are included, i.e., those obtained when 800 grams alfalfa hay and 112 grams soybean oil meal were considered as the basal ration.

Because of the absence of any recent compilation giving full detailed data for digestion experiments on soybean products, the original publications were examined and their essential features summarized in the Appendix, Table 22, which is intended to cover all experiments, both foreign and American, reported up to May, 1927. The table includes a description of the ration fed, individual data for each animal, and the length of collection period, as well as the date and reference to the experimenter. It is therefore suited to a study of the extent of variation occurring in digestion coefficients obtained under different conditions.

The Digestibility of Soybean Products

The average percentage composition and the gross energy content of all feeds used in this investigation are shown in Table 14. There is also listed for comparison the percentage composition of the same feeds as found in Henry and Morrison's "Feeds and Feeding."[21*] From such a comparison, it may be considered that all feeds used were fairly representative samples of feed obtainable in the corn belt (except the alfalfa fed in the first part of Period VIII, referred to on page 263).

While the investigation was concerned chiefly with a study of the soybean plant, information was obtained also for oat straw and alfalfa hay. With the exception of ether extract, which is of insignificant value in the feeding of roughages, all of the nutrients of alfalfa hay are digested to a considerably higher extent than are those of soybean hay. Both soybean straw and oat straw are inferior to soybean hay and alfalfa hay in digestibility, while oat straw is considerably superior to soybean straw.

The digestibility of the nutrients in the combined rations was invariably increased whenever alfalfa hay was substituted for either soybean straw or oat straw in a ration containing either soybean oil meal or whole soybeans. In a ration containing approximately .5 pound of whole soybeans and 1.75 pounds of oat straw, the coefficients for dry matter, crude protein, nitrogen-free extract, ether extract, and crude fiber were 48, 71, 43, 67, and 43 in the order named. The same coefficients for a ration in which the oat straw was replaced by approximately the same amount of alfalfa hay were 69, 81, 77, 80, and 47. The coefficients for a ration of approximately .5 pound of soybean oil meal and 2.0 pounds of soybean straw were 55, 68, 64, 59, and 43, while for a ration containing .25 pound of soybean oil meal and 1.75 pounds of alfalfa hay the average digestion coefficients were 64, 78, 76, 55, and 35 respectively; for a ration containing .75 pound of soybean oil meal and 1.75 pounds of alfalfa hay, the average coefficients were, in order, 65, 78, 78, 70, and 39.

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investigators with sheep on a ration of .75 pound of soybean meal and 1.5 pounds of timothy rowen hay. Omitting these two misquoted series of results, the average digestion coefficients for soybean meal become 90.9 for protein, 92.7 for ether extract, 67.8 for crude fiber, and 79.5 for nitrogen-free extract.

TABLE 14.—CHEMICAL COMPOSITION OF FEEDS USED COMPARED WITH AVERAGE ANALYSES FOR THOSE FEEDS

	Number of analyses	Dry matter	Crude protein	N-free extract	Ether extract	Crude ash	Crude fiber	Gross energy per kg.
		pct.	*pct.*	*pct.*	*pct.*	*pct.*	*pct.*	*therms*
Soybean hay, 1923	4	88.2	14.8	34.9	3.5	8.2	26.8	3.82
Soybean hay, Henry and Morrison[a]	23	91.4	16.0	39.1	2.8	8.6	24.9	....
Soybean straw, 1923	8	88.9	4.0	38.9	1.0	5.0	40.0	3.77
Soybean straw, Henry and Morrison	8	88.1	5.6	37.2	1.7	6.8	36.8	....
Soybean seed, 1923	4	88.4	38.9	21.9	16.2	4.6	6.7	4.63
Soybean seed, 1925	2	94.0	32.6	29.1	19.5	5.9	6.9	5.21
Soybean seed, Henry and Morrison	121	90.1	36.5	26.5	17.5	5.3	4.3	....
Soybean oil meal, 1923	4	88.7	38.8	32.6	4.7	6.5	6.1	4.29
Soybean oil meal, 1925	7	90.7	39.5	30.7	5.6	6.5	8.4	4.36
Soybean oil meal, Henry and Morrison	10	89.5	43.2	29.5	6.6	4.9	5.3	....
Oat straw, 1923	8	93.4	4.8	43.4	2.1	8.5	34.7	4.00
Oat straw, Henry and Morrison	41	88.5	3.6	40.8	2.4	5.4	36.3	....
Alfalfa hay, 1925	10	91.5	18.0	35.7	2.4	9.0	26.4	4.04
Alfalfa hay, Henry and Morrison	250	91.4	14.9	37.3	2.3	8.6	28.3	....

[a]Henry and Morrison, "Feeds and Feeding," 1923.

TABLE 15.—A COMPARISON OF DIGESTION COEFFICIENTS CALCULATED ON BASIS OF NUTRIENTS OFFERED AND CONSUMED

	Soybean hay		Soybean straw		Oat straw and whole soybeans		Oat straw		Soybean straw and soybean oil meal	
	Consumed	Offered	Consumed	Offered	Consumed	Offered	Consumed	Offered	Consumed	Offered
Dry matter	54	47	40	28	48	40	46	36	55	52
Crude protein	69	64	15	11	71	65	14	9	68	64
N-free extract	64	56	54	39	43	35	45	35	64	61
Ether extract	62	59	15	11	67	63	23	19	59	58
Crude fiber	35	27	32	20	43	32	57	44	43	40

From Table 13 it appears that the average digestibility of the dry matter, crude protein, and nitrogen-free extract was very nearly the same for the four rations used in 1925. Some variations occurred in the digestibility of crude fiber, but it is doubtful whether the average differences are significant, while the digestibility of the ether extract varied directly with the fat content of the ration. For rations consisting of 800 grams of alfalfa hay alone, and for those containing 800 grams of alfalfa hay combined with whole soybeans (225 grams) or with soybean oil meal in varying amounts (112 and 340 grams), the average coefficients of digestion of dry matter were, in the order named, 65, 69, 64, and 65; those for crude protein, 78, 81, 78, and 78; for nitrogen-free extract, 76, 77, 76, and 78; for crude fiber, 48, 47, 35, and 39; and for ether extract, 51, 80, 55, and 70. It seems remarkable that these four rations should possess so similar a digestibility for most of the nutrients.

Significance of Refused Feed in Digestion Experiments

The coefficient of digestibility of a nutrient is ordinarily expressed as that percentage of the nutrient consumed which does not appear in the feces. Obtained in this manner, however, it is normally applied to the feed as fed in the calculation of the digestible nutrients of rations. This brings up the question, Do the coefficients thus obtained represent the digestibility of the feed fed under practical conditions?

Under practical conditions of feeding, animals naturally do not eat the coarse, woody, and unpalatable portions that may be found in roughages. An examination of the mangers in most any barn will substantiate this statement. Thus Nevens[31*] found that a close relationship existed between the thickness of planting soybeans and the proportion of refused hay (stems). Feeding trials showed that while 120 pounds per ton were refused from hay grown in plots on which 1.25 bushels of soybeans had been sown, 360 pounds per ton were refused from hay taken from the plots on which .5 bushel of seed had been sown. If, under practical conditions, a certain amount of the roughage is left uneaten, digestion coefficients based on the amounts of the nutrients offered, instead of upon the amounts of nutrients consumed, would be of considerable importance tho subject to variation depending upon the condition of the feed.

While the data in this investigation may not be sufficient to justify any general conclusions in this connection, a comparison of the digestion coefficients based upon the nutrients consumed and on the nutrients offered is of interest. Therefore, in addition to the usual method of calculating digestion coefficients, coefficients were also calculated on the basis of the nutrients offered. The two sets of coefficients are averaged for each ration fed in the 1923 investigation in Table 15. As would be expected, all coefficients calculated on the basis of nutrients

TABLE 16.—DIGESTIBLE NUTRIENTS PER 100 POUNDS OF FEED OR RATION COMPUTED BY MEANS OF COEFFICIENTS SUMMARIZED IN TABLE 15[a]

Ration	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber	Total digestible nutrients
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Soybean hay	(41.4)	(9.5)	(19.5)	(2.1)	(7.2)	(40.9)
	49.1	11.5	23.2	2.5	8.8	49.1
Soybean straw	(24.1)	(.45)	(14.5)	(.12)	(7.8)	(23.0)
	36.0	.69	22.0	.18	12.1	35.2
Oat straw and whole soybeans	(36.6)	(8.3)	(13.7)	(3.5)	(8.4)	(38.3)
	43.8	10.3	16.7	4.2	10.4	46.9
Oat straw	(34.0)	(.42)	(14.8)	(.33)	(16.4)	(32.4)
	43.6	.69	19.0	.43	21.0	41.7
Soybean straw and soybean oil meal	(47.5)	(6.9)	(23.8)	(1.0)	(13.6)	(46.6)
	51.0	8.0	25.1	1.1	14.3	49.9

[a]The figures given in parentheses were obtained by the use of the coefficients of digestion based on the quantity of feed offered. They therefore represent the amounts of digestible nutrients per 100 pounds of feed or ration. The figures not enclosed in parentheses were obtained by the use of the coefficients based on the quantity of feed consumed. They represent, therefore, the digestible nutrients per 100 pounds of consumed (edible?) feed or ration.

offered are lower than those calculated on the basis of nutrients consumed. The greatest differences, of course, relate to the less palatable straws and, among the different nutrients, to the crude fiber, but it should be noted that all other nutrients are considerably affected also. These differences are, perhaps, better shown in Table 16, in which are tabulated the average number of pounds of digestible nutrients per 100 pounds of feed or ration.

In Table 16 the figures set off in parentheses do not include the nutrients in the refused feed; the others do. The figures in the last three lines for alfalfa hay, whole soybeans, and soybean oil meal, however, would be the same on both bases since the nutrients offered were also consumed. In calculating the digestible nutrients in soybean hay (offered), soybean straw (offered), oat straw (offered), alfalfa hay, whole soybeans, and soybean oil meal, the average percentage composition of these feeds obtained in this investigation and the coefficients of digestion tabulated in Table 15 on the basis of nutrients offered were used. In calculating the digestible nutrients in the combined rations offered and consumed, the average percentage composition of these rations as given in Table 8 and the corresponding coefficients given in Table 15 were used.

It can be seen from Table 16 that the usual method of calculating the amounts of digestible nutrients indicates a much greater utilization of the nutrients than is actually the case when allowance is made for the refused, and presumably inedible, portions. The percentage of total digestible nutrients in the soybean hay in these experiments was actually 42.2 percent, as compared with 49.1 percent as ordinarily computed, neglecting the inedible fraction. The percentage of total digestible nutrients in soybean straw was actually 23.6 percent, as

compared with the customary computation of 35.2 percent, a difference of 11.6 percent. Similar differences may be noted for the other rations.

The question whether the amounts of feeds refused in this experiment were excessive should be considered at this point. The following were the average amounts of feeds fed and the average percentages of dry matter refused from each ration: of 2.25 pounds of soybean hay an average of 13.9 percent of the dry matter was refused; of 2.5 pounds of soybean straw, 31.1 percent was refused; of about 1.75 pounds of oat straw and .5 pound of whole soybeans, 22.3 percent of the dry matter of the oat straw was not eaten; of about 2 pounds of oat straw, 22.2 percent was refused; and of about 2 pounds of soybean straw and .5 pound of soybean oil meal, 6.9 percent of the dry matter of the soybean straw proved inedible. The feeding experiment of Nevens,[31*] in which, depending upon the coarseness of the hay, from 6 to 18 percent of soybean hay was refused by dairy cattle, has been mentioned. In a similar experiment with sheep Kammlade[32*] fed one lot of ewes 3.12 pounds of alfalfa hay, of which 1.7 percent was refused. A second lot receiving 3.77 pounds of soybean hay, refused an average of 15.2 percent. When a ration of .98 pound of grain and 3.01 pounds of alfalfa hay was fed, less than 1 percent was refused, but a ration of .87 pound of grain and 4.26 pounds of soybean hay was refused to the extent of 20.7 percent. In an experiment with soybean straw Kammlade found that more than 40 percent was refused.

An examination of a number of the digestion experiments previously mentioned in this bulletin showed that some feed was refused in practically all cases in which the animals were receiving approximately full feeds of a ration containing a roughage. In Kellner's experiment on soybean hay[3*] one sheep refused 8.5 and the other 18.0 percent of the dry matter from 1 kilogram of the hay. In an experiment with soybean hay Emery and Kilgore[5*] reported that a goat which received 1,200 grams daily refused 28.1 percent of the dry matter, and a cow which received 16 pounds daily refused 14.7 percent. From a ration of 400 grams each of soybean hay and English hay, Lindsey[6*] found 14.4 percent of the dry matter of soybean hay refused by one sheep, and in another experiment[11*] one sheep, offered 2,000 grams of green soybean fodder and 400 grams of English hay, refused 7.2 percent of the dry matter. In the experiments reported by Phelps[13, 14*] on soybean fodder, various but small amounts of feed up to 6.5 percent were refused.

Finally, Emery and Kilgore[16*] observed that one of two goats refused 6.2 percent and the other 31.5 percent of the dry matter from a ration of 6 pounds of soybean silage, while in Hopkins' experiment with steers on the same feed,[17*] from 11.7 to 15.5 percent of the dry matter was refused from rations varying from 48 to 66 pounds of silage per head daily.

A consideration of these experiments reveals two facts: first, that the amounts of refused feed in the present investigation were not abnormal for the feeds used; and second, that the digestion coefficients calculated in the usual manner may be of little value in estimating the amounts of digestible nutrients in certain feeds in so far as they contain inedible portions. While it may be questioned whether the refusal of oat straw by experimental animals indicates anything more than the offering of more of this unpalatable feed than the animal cares to consume, the situation with reference to soybean roughages is evidently different. The general refusal of parts of these roughages, no matter how little is fed, as well as the appearance of the refused portions, demonstrates that soybean roughages may be considered as being only partially edible. It will always remain a difficult task, therefore, to estimate the digestible nutrients in samples of these feeds by *any* set of digestion coefficients since the inedible fraction will vary. The nutrients in the inedible fraction obviously are as worthless to the animal as the edible but indigestible or undigested nutrients.

Significance of Indirectly Calculated Coefficients of Digestibility

The method of calculating the digestible nutrients of a concentrate for ruminants, by subtracting from the digestible nutrients in a mixed ration the amounts computed for the basal ration as determined by a previous trial, is based upon the assumption that the addition of the concentrate to the basal ration does not affect the digestibility of the nutrients in the basal ration and *vice versa*. That this assumption is not sound from the physiological point of view has long been recognized, and that it is not correct in practice as regards certain nutrients in certain combinations of feeds was noted by some of the early workers, for example, Hirschler in 1886,[33*] Gottwald in 1888,[34*] and Kuehn in 1894.[35*]

In reviewing the literature it soon becomes evident that, in general, the nutrients present in the smallest amounts are the most affected. Thus, fat and crude fiber are especially influenced, while nitrogen may be affected in the feeds low in this element. Dry matter and nitrogen-free extract are usually but little influenced; the latter because it is usually present in considerable amounts, and the former because it reflects both the depressing and elevating effects on the several nutrients.

It is a well-known fact among investigators in animal nutrition that determinations of the availability or digestibility of the ether extract of feeds are often unsatisfactory and as a rule are quite unreliable when obtained by indirect calculations. One of the chief contributory factors is the influence of the metabolic products of the feces, particularly the bile residues, while the presence of fat in only small

quantities in most concentrate feeds magnifies any influence of these disturbing factors. Armsby[36*] states: "Even with the herbivorous animals, however, the presence of the so-called metabolic products of the feces may give rise to serious errors in the determination of the real digestibility of some ingredients of the food, notably fat and protein." The determination of the digestibility of ash is so notably unreliable that only occasionally does an investigator attempt to calculate it. Forbes[37*] states that we have no satisfactory means for determining the digestibility of the mineral nutrients and that it is not warrantable to speak of their digestibility.

The work of Eckles,[38*] of Mumford, Grindley, Hall, and Emmett,[39*] and of Snyder[40*] seems to indicate an inverse relationship between the quantity of crude fiber in feeds and the digestibility of the nitrogen-free extract, altho Ewing and Wells,[41*] in an excellent review of the literature and a study of what they very aptly term "the associative action of feeds," found that with a decrease in the amount of crude fiber in the form of silage there was a decrease, instead of an increase, in the digestibility of the nitrogen-free extract.

Ewing and Wells also found, in agreement with several early workers, that starch when fed in excessive amounts seemed to exert a depressing effect upon the digestibility of the nitrogen and crude fiber, even when the excess was not great. The depression of the digestibility of nitrogen and crude fiber was often accompanied by a rise in the digestibility of fat, which was quite noticeable in the high starch rations. At the same time they noted a lowering in the digestibility of the nitrogen-free extract of 10 percent or more when starch was introduced into the ration in excessive amounts. Atwater,[42*] on the other hand, in connection with reports of digestion experiments with men, says:

> "Increasing the quantity of either carbohydrates or fat above those common in the ordinary diet had no effect upon the availability of the other nutrients of the diet, while the availability of the fat or carbohydrates in the experiment in which either was used in large quantities was as large as, or larger than in the experiments in which the quantities were more nearly like those in the ordinary diet."

Other general researches or discussions of the influence of one food upon another are those of Rubner,[43*] of Atwater,[44*] of Ewing, Wells, and Smith,[45*] of Fraps,[30*] and of Forbes, Beegle, Fritz, and Mensching,[12*] all of whom agree in reaching conclusions similar to that expressed by Dietrich and Grindley[46*] as follows:

> "The coefficients of digestibility obtained for a single feed by calculation from the data obtained for a combination of feeds are not reliable, especially when the single feed has been fed in comparatively small quantities. By this method of calculation all of the difference between the values for the single and the corresponding values for the combined feeds is credited to the single feed, whereas it is probable that in the combined ration each feed exerts an influence upon the digestibility of the other."

In the last sentence of this quotation is found the explanation of the fact that coefficients of digestion obtained by the indirect calculation may indicate a digestibility of less than nothing or more than 100 percent. However, such an associative effect between feeds need not result in impossible digestion coefficients, and the absence of impossible results of such indirect calculations is no indication that associative relations are not operating between the added feed and the basal ration.

Fraps,[30*] in connection with his compilation of American digestion experiments, made a statistical study of the variations in the digestibility of all feeds on which three or more tests had been made. By dividing the "percent error" found in Table 1 of Fraps' bulletin by .6745, the coefficients of variation are obtained. This was done by the authors, and the coefficients of variation for all feeds on which the digestibility had been directly determined and for all feeds on which the digestibility had been indirectly determined, were averaged separately. The average coefficients of variation for the directly obtained coefficients of digestion are: 19 for protein, 18 for fat, 11 for crude fiber, and 7 for nitrogen-free extract. Those for the indirectly obtained coefficients are: 29 for protein, 21 for fat, 63 for crude fiber, and 8 for nitrogen-free extract. The errors that may be incurred in the indirect method of calculation are again clearly emphasized.

The associative action of feeds was very pronounced in the present investigation. Consider the indirectly determined coefficients of digestion for whole soybeans in Period III, in which 12 sheep were fed an average of .5 pound of whole soybeans and 1.75 pounds of oat straw, as well as in Period VII, in which 6 sheep received the same amount of whole soybeans while the oat straw was replaced by approximately the same amount of alfalfa hay. These variations are best shown in Table 17, which gives the maximum and minimum coefficients and the average for each nutrient.

It appears, from a consideration of these data, that of all the nutrients of soybeans crude protein only is unaffected in estimated digestibility by the change from oat straw to alfalfa hay. With all other nutrients the digestibility, calculated indirectly, is greatly increased. The variations in the digestibility of any nutrient (with the possible exception of crude protein) in each period are very large, and if the two periods are considered together, the average coefficients, with the same exception, are evidently of little if any value. Undoubtedly an associative action is exerted in digestion between soybeans and the roughages with which they are fed. It is equally true that indirect calculations of the digestibility of soybeans under these conditions give purely fictitious values, with the possible exception of the digestion coefficients for protein.

A similar tabulation of the variations in the indirectly calculated digestion coefficients for the nutrients of soybean oil meal is presented

TABLE 17.—VARIATIONS IN DIGESTION COEFFICIENTS FOR WHOLE SOYBEANS AS OBTAINED INDIRECTLY

Period	Ration	Number of Sheep	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
III	Whole soybeans, 228 grams (fed with oat straw, 779 grams)	12	32 to 75 53	82 to 97 90	−61 to +74 31	70 to 100 84	−307 to −33 −128
VII	Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams)	6	75 to 94 84	82 to 95 88	74 to 94 82	89 to 102 94	−90 to +94 19

TABLE 18.—VARIATIONS IN DIGESTION COEFFICIENTS FOR SOYBEAN OIL MEAL AS OBTAINED INDIRECTLY

Period	Ration	Number of sheep	Dry matter	Crude protein	N-free extract	Ether extract	Crude fiber
V	Soybean oil meal, 225 grams (fed with soybean straw, 910 grams)	12	101 to 132 114	81 to 96 88	77 to 149 112	64 to 120 95	132 to 534 323
VIII	Soybean oil meal, 112 grams (fed with alfalfa hay, 800 grams)	6	10 to 86 56	55 to 107 80	53 to 103 81	17 to 100 64	−280 to 0 −187
IX	Soybean oil meal, 340 grams (fed with alfalfa hay, 800 grams)	6	53 to 73 66	72 to 82 79	81 to 91 86	72 to 94 82	−168 to 0 −50
IX	Soybean oil meal, 228 grams (fed with alfalfa hay, 800 grams, and soybean oil meal, 112 grams)	6	44 to 74 64	71 to 85 80	81 to 94 88	75 to 119 96	−47 to 135 86

in Table 18. The same sort of variations that were observed in the case of whole soybeans are also shown for soybean oil meal. The extremely wide variations exhibited by Period VIII are not entirely attributable to the method of indirect calculation, as has already been explained. The degree to which digestion coefficients may be influenced by different basal rations is well illustrated by the coefficients for crude fiber. For soybean oil meal when fed with soybean straw they vary from 132 to 534, with an average of 323, and for the same meal when fed with alfalfa hay (Period IX) they vary from 0 to —168, with an average of —50. In other words, simply changing the basal ration changes a coefficient from positive 323 to a negative 50. As Forbes[12*] says (page 233), in referring to similar results obtained with swine, such a determination is certainly, "to borrow an expression from Thudichum, 'a ceremonious delusion'." Such values are positive evidence of "associative action of feeds" and demonstrate that an indirectly determined digestion coefficient may possess no significance whatever. Thus, a coefficient determined indirectly from a certain mixed ration may not be applicable with any degree of certainty to any other ration.

A rather common expedient used to avoid the reporting of impossible digestion coefficients is the procedure of reporting as 100 all coefficients obtained above this value, and of reporting all negative coefficients as zero. For example, Emery and Kilgore[5*] determined the digestibility of soybean hay, using a goat and a cow. The average digestion coefficient for ash was reported as 23.70, but the individual coefficients were —104 and 47.41, obviously the average of 23.70 is the average of 0 and 47.41. Concerning such a procedure, Forbes[12*] says (page 234):

> "Digestion coefficients of less than nothing, and more than 100 percent, show that the determination of digestibility of supplementary foods by difference, in the usual way, is not free from objection, since the supplement affects the digestibility of the basal ration, which the method assumes to be constant. It seems to us more nearly correct, however, to use the figures obtained than to call all minus coefficients zero, and to give a value of 100 percent to all those which seem to be above that figure."

However, it may be argued with greater force, in our opinion, that the obtaining of such impossible coefficients is *prima facie* evidence that the method of computation is incorrect and that the results obtained with it, in such cases at least, are of no demonstrable value.

In the determination of digestion coefficients by difference, two things are illustrated by Periods VIII, IX, and X. First, as the proportion of concentrates increases, the variations in the digestion coefficients decrease, and the coefficients themselves approach more nearly the coefficients found when the concentrate is fed alone. Second, more consistent and apparently more reliable coefficients are obtained when the basal ration contains a small amount of the concentrate.

Thus from Period IX, when the digestibility of the 228 grams of soybean oil meal was calculated considering the basal ration to be 112 grams of soybean oil meal and 800 grams of alfalfa hay, the coefficients were more consistent than they were when the digestibility of the 340 grams of soybean oil meal was calculated considering the basal ration to be 800 grams of alfalfa hay alone. In the determination of digestion coefficients of the nutrients of a concentrate for ruminants, the basal ration is usually a roughage alone; from the above considerations better results would perhaps be obtained if the basal ration contained a small amount of the concentrate.

The not infrequent occurrence of impossible digestion coefficients when the digestibility of concentrates by ruminants is determined indirectly on the assumption that it, as well as that of the basal ration, is unaffected by their admixture in a ration, testifies to the inaccuracy of this basic assumption. Furthermore, the variable digestion coefficients calculated for concentrates when added to different basal rations possess the same significance. Finally, the securing of possible coefficients (between 0 and 100), or of coefficients such as would be expected for a given concentrate, is no evidence that they have not to some extent been vitiated by the existence of associative relations in digestion between the concentrate and the basal ration with which it was fed. It thus appears that indirectly determined coefficients of digestion are unreliable and may be grossly in error. Rather than attempt indirect determinations of concentrates by a method known to be inaccurate, it may be far better to concern oneself with the digestibility of the concentrate in combinations with those roughages and other feeds with which it is most commonly fed.

Metabolizable Energy of Soybean Products Determined for First Time

Thruout this investigation all digestion trials were also metabolism trials. The daily excretion of urine was weighed, aliquoted, and analyzed for total nitrogen and gross energy. The gross energy of the feces and all samples of feeds and orts was also determined. Thus by using average factors for the calculation of the loss of energy in the methane, all data necessary for the calculation of the metabolizable energy of the various feeds and rations were available. The values for the metabolizable energy of soybean products obtained in this investigation are the only available determinations in this country. A summary of the metabolizable energy of all feeds and rations fed during the entire investigation is presented in Table 19.

The availability, as metabolizable energy, of the gross energy of the feeds and rations is, in decreasing order, as follows (page 278):

TABLE 19.—SUMMARY OF THE AVERAGE METABOLIZABLE ENERGY VALUES OF ALL FEEDS FED IN BOTH INVESTIGATIONS

Period	Feed or ration	Number averaged	Kinds	Percent of gross energy	Per kg. dry matter	Per kg. digestible organic matter	Per kg. total digestible nutrients
					therms	*therms*	*therms*
I	Soybean hay, 1,051 grams (1923)	12	1	43.76	1.90	3.73	3.49
II	Soybean straw, 1,135 grams (1923)	12	1	32.17	1.40	3.57	3.55
IV	Oat straw, 900 grams (1923)	12	1	36.75	1.57	3.61	3.57
VI	Alfalfa hay, 800 grams (1925)	6	1	54.26	2.44	4.06	3.94
III	Whole soybeans, 228 grams, and oat straw, 779 grams (1923)	12	1	40.97	1.89	4.18	3.65
VII	Whole soybeans, 225 grams, and alfalfa hay, 800 grams (1925)	6	1	59.37	2.75	4.33	3.91
V	Soybean oil meal, 225 grams, and soybean straw, 910 grams (1923)	12	1	44.97	1.92	3.69	3.59
VIII	Soybean oil meal, 112 grams, and alfalfa hay, 800 grams (1925)	6	1	55.97	2.51	4.15	3.97
IX	Soybean oil meal, 340 grams, and alfalfa hay, 800 grams (1925)	6	1	54.94	2.47	4.02	3.86
III	Whole soybeans, 228 grams (fed with oat straw, 779 grams) (1923)	6	1	.....	2.82	4.60	3.42
VII	Whole soybeans, 225 grams (fed with alfalfa hay, 800 grams) (1925)	6	1	.....	3.83	5.06	3.84
....	Whole soybeans, average	12	2	.....	3.35	4.83	3.63
V	Soybean oil meal, 225 grams (fed with soybean straw, 910 grams) (1923)	12	1	.....	3.71	3.66	3.46
IX	Soybean oil meal, 228 grams (fed with alfalfa hay, 800 grams, and soybean oil meal, 112 grams) (1925)	6	1	.....	2.88	3.65	3.37
X	Soybean oil meal, 450 grams (alone) (1925)	1	1	68.18	3.49	4.22	3.94
....	Soybean oil meal, average	19	2	.....	3.44	3.69	3.46

	perct.
Soybean oil meal, 450 grams (fed alone)	68.2
Soybeans, 225 grams, and alfalfa hay, 800 grams	59.4
Soybean oil meal, 112 grams, and alfalfa hay, 800 grams	56.0
Soybean oil meal, 340 grams, and alfalfa hay, 800 grams	54.9
Alfalfa hay, 800 grams	54.3
Soybean oil meal, 225 grams, and soybean straw, 910 grams	45.0
Soybean hay, 1,051 grams	43.8
Soybeans, 228 grams, and oat straw, 779 grams	41.0
Oat straw, 900 grams	35.8
Soybean straw, 1,135 grams	32.2

The metabolizable energy per kilogram of digestible organic matter in all feeds and rations fed, including the calculated values for the concentrates, is, in decreasing order, as follows:

	therms
Soybeans, 225 grams (with alfalfa hay, 800 grams)	5.06
Soybeans, 228 grams (with oat straw, 779 grams)	4.60
Soybeans, 225 grams, and alfalfa hay, 800 grams	4.33
Soybean oil meal, 450 grams (fed alone)	4.22
Soybeans, 228 grams, and oat straw, 779 grams	4.18
Soybean oil meal, 112 grams, and alfalfa hay, 800 grams	4.15
Alfalfa hay, 800 grams	4.06
Soybean oil meal, 340 grams, and alfalfa hay, 800 grams	4.02
Soybean hay, 1,051 grams	3.73
Soybean oil meal, 225 grams, and soybean straw, 910 grams	3.69
Soybean oil meal, 225 grams (with soybean straw, 910 grams)	3.66
Soybean oil meal, 228 grams (with alfalfa hay, 800 grams, and soybean oil meal, 112 grams)	3.65
Oat straw, 900 grams	3.61
Soybean straw, 1,135 grams	3.57

Expressed in this manner there appears to be considerable difference in the amount of metabolizable energy in different feeds and rations. For the non-nitrogenous roughages, oat straw and soybean straw, there is an average of 3.59 therms of metabolizable energy per kilogram, or 1.63 therms per pound of digestible organic matter. This value compares favorably with Armsby's[47*] value of 1.588 therms per pound of digestible organic matter in roughages in general for ruminants. For the oat straw alone the value of 3.61 therms per kilogram of digestible organic matter was obtained. Armsby[49*] quotes from Kellner the value of 3.740 therms per kilogram of digestible organic matter in oat straw obtained by cattle. There are no results with sheep reported.

For the nitrogenous roughages, soybean hay and alfalfa hay, the average is 3.90 therms per kilogram or 1.77 therms per pound of digestible organic matter. For the alfalfa hay alone the value of 4.06 therms per kilogram or 1.85 therms per pound of digestible organic matter was obtained. Armsby[49*] quotes from Tangl *et al* the value of 4.467 therms obtained with sheep; and from his own work with cattle, the value of 3.605 therms. The value obtained in this investigation is near the average of these two reported values. Christensen and Hop-

per[48*] obtained an average value with two steers of 1.700 therms per pound of digestible organic matter, a value slightly lower than obtained with the sheep in the present investigation.

The average value for whole soybeans is 4.83 therms per kilogram or 2.19 therms per pound of digestible organic matter. This value is considerably higher than Armsby's[47*] calculated average value of 1.814 therms per pound of digestible organic matter in concentrates with more than 5 percent digestible fat. It is also considerably higher than the value of 3.977 therms per kilogram of digestible organic matter, quoted by Armsby[49*] from Völtz *et al,* for palm-nut meal with sheep, altho it checks almost exactly the value of 4.849, obtained by the same authors with steers.

While the value of 4.22 therms of metabolizable energy per kilogram of digestible organic matter was obtained in the single trial in which soybean oil meal was fed alone, the average of all trials, including those in which the metabolizable energy of the soybean oil meal was calculated by difference, is 3.69 therms per kilogram or 1.67 therms per pound of digestible organic matter. This value is lower than Armsby's average values of 1.996–2.177 for oil meals, altho the directly determined value of 4.22 therms per kilogram or 1.92 therms per pound agrees very closely. The literature does not contain any experiments in which the metabolizable energy of an oil meal has been determined either directly or indirectly for ruminants.

When the metabolizable energy of a feed is related to the digestible organic matter in the feed, different feeds give widely different values. Much of this variability is probably due to the fact that digestible fat contains approximately 2.25 times as much metabolizable energy as either protein or carbohydrates. When the metabolizable energy is related to the so-called "total digestible nutrients," in which digestible fat is expressed in carbohydrate equivalents, the differences in the metabolizable energy values of different feeds become much less. For example, the metabolizable energy values of all feeds summarized in Table 19, when expressed in terms of metabolizable energy per kilogram of digestible organic matter, vary from 5.06 for a ration of 225 grams of whole soybeans (calculated from the ration containing in addition 800 grams of alfalfa hay) to 3.57 for a ration of soybean straw. When expressed in therms per kilogram of total digestible nutrients, the metabolizable energy varies only from 3.97 for a ration of 112 grams of soybean oil meal and 800 grams of alfalfa hay to 3.37 for 228 grams of soybean oil meal (calculated from a ration containing in addition 800 grams of alfalfa hay and 112 grams of soybean oil meal).

The indirect determination of the metabolizable energy of a concentrate is, of course, open to the same errors as the indirect determination of its digestibility, but since the metabolizable energy involves all of the organic nutrients, the effect of the errors on the different nu-

trients may be expected to be greatly reduced by compensation. Thus, the values in the last column of Table 19 for any one feed vary only slightly according to the method of their calculation. However, the estimated metabolizable energy values of soybeans and soybean oil meal are, with one exception, greater when computed from the results obtained with an alfalfa hay ration than from the results of a ration containing oat straw or soybean straw. It may be significant that the single result obtained with soybean oil meal alone checks closely with the values computed from the rations containing alfalfa hay.

SUMMARY AND CONCLUSIONS

The experimental work reported in this bulletin is concerned with the determination of the coefficients of digestibility of the nutrients and the metabolizable energy of soybean products for sheep. The soybean products studied were soybean hay, soybean straw, whole soybeans, and soybean oil meal. During the last twenty-three years there have been reported but two digestion experiments with soybean products; one was concerned with a mixed ration containing soybean hay for ruminants, and the other was concerned with soybeans for swine. There have been no American digestion experiments with either soybean straw or soybean oil meal. The metabolizable energy values for these products obtained in this investigation constitute the only published values, while the metabolizable energy value obtained for soybean oil meal is the only available directly determined value for an oil meal of any kind.

The experiments were carried out during a part of 1923 and a part of 1925. During 1923 the digestibility and metabolizable energy of five rations were determined, using with each ration 12 sheep, a number three times as large as has ever been used in a single digestion experiment with soybean products on ruminants. During 1925 the digestibility and metabolizable energy of five rations were determined using 6 sheep.

Digestion coefficients for soybean hay, soybean straw, alfalfa hay, oat straw, and of rations containing soybean straw and soybean oil meal, oat straw and whole soybeans, alfalfa hay and whole soybeans, and alfalfa hay and soybean oil meal at two different levels, were obtained directly, as was also the metabolizable energy of each. The digestion coefficients and the metabolizable energy of soybean oil meal were obtained directly with one sheep. Indirect calculations were made in the usual manner of the digestibility and metabolizable energy of soybeans and soybean oil meal. The average results obtained are tabulated in Tables 13 and 19.

It appears that certain roughages, because of their physical character, are only partially edible by farm animals. Digestion trials with such feeds involve variable amounts of orts and give more or less

unsatisfactory digestion coefficients. The coefficients obtained evidently apply to the *edible* portion of the feed only, and should not be used in connection with weights of feed offered in computing the digestible nutrients of rations. Such coefficients do not have a general applicability, since the inedible portion of the roughage will vary with the conditions under which it was grown or prepared for the animal. Soybean straw and soybean hay are roughages of this character, and the use of the digestion coefficients and metabolizable energy values obtained for them must be tempered by the above considerations.

From a critical study of the results obtained in this investigation, as well as those in numerous previous investigations, the authors feel that coefficients of digestion obtained by the usual method of indirect calculation are in general unreliable. Apparently the digestibility of concentrate feeds cannot be satisfactorily determined with ruminants, since they exert variable associative effects in digestion when combined in rations with other feeds. It is recommended that, in place of attempting such unsatisfactory determinations, the digestibility of concentrates for ruminants, combined with those feeds with which they are commonly fed, be investigated. Only the directly determined results on the combined rations can be considered significant.

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APPENDIX

TABLE 20.—NITROGEN BALANCES: INVESTIGATION OF 1923

Sheep No.	Nitrogen in feed consumed	Nitrogen in feces	Nitrogen in urine	Nitrogen balance
		Period I—Soybean hay		
	grams	*grams*	*grams*	*grams*
130	165.3	51.68	92.0	+21.62
131	159.2	49.92	86.0	+23.28
132	151.0	41.12	91.0	+18.88
133	151.5	48.00	96.0	+ 7.50
134	159.8	55.84	99.0	+ 4.96
135	149.9	45.44	95.0	+ 9.46
137	166.4	59.68	108.0	− 1.28
138	151.5	47.68	99.0	+ 4.82
139	159.8	51.52	109.0	− .72
136	171.0	51.52	106.0	+13.48
140	177.0	52.48	117.0	+ 7.52
141	176.5	47.68	109.0	+19.82
Average	161.6	50.21	100.6	+10.78
		Period II—Soybean straw		
130	34.6	31.36	23.0	−19.76
131	31.0	33.12	26.0	−28.12
132	25.9	21.28	27.0	−22.38
133	46.1	33.92	22.0	− 9.82
134	48.5	40.64	23.0	−15.14
135	41.0	28.48	25.0	−12.48
136	42.9	37.92	25.0	−20.02
137	43.8	35.04	28.0	−19.24
138	37.4	33.28	22.0	−17.88
139	39.5	35.68	23.0	−19.18
140	38.9	37.12	30.0	−28.22
141	38.6	29.28	20.0	−10.68
Average	39.02	33.09	24.50	−18.58
		Period III—Oat straw and whole soybeans		
	grams	*grams*	*grams*	*grams*
130	134	45	99	−10
131	132	40	97	− 5
132	136	50	104	−18
133	138	43	94	+ 1
134	126	40	96	−10
135	125	33	97	− 5
136	135	36	80	+19
137	133	36	84	+13
138	132	31	72	+29
139	136	36	95	+ 5
140	134	35	93	+ 6
141	135	36	90	+ 9
Average	133	38	92	+ 3

TABLE 20.—*Concluded*

Sheep No.	Nitrogen in feed consumed	Nitrogen in feces	Nitrogen in urine	Nitrogen balance
Period IV—Oat straw				
130	41	39	26	−24
131	44	36	25	−17
132	47	38	28	−19
133	44	38	29	−23
134	44	39	28	−23
135	33	24	25	−16
136	33	34	24	−25
137	31	33	25	−27
138	31	28	27	−24
139	42	35	26	−19
140	39	34	27	−22
141	33	31	26	−24
Average	39	34	26	−22
Period V—Soybean straw and soybean oil meal				
130	137	46	88	+ 3
131	138	44	96	− 2
132	134	40	89	+ 5
133	136	42	85	+ 9
134	135	46	86	+ 3
135	132	42	71	+19
136	127	43	61	+23
137	126	38	80	+ 8
138	126	40	83	+ 3
139	141	46	80	+15
140	138	42	92	+ 4
141	140	42	92	+ 6
Average	134	43	84	+ 8

TABLE 21.—NITROGEN BALANCES: INVESTIGATION OF 1925

Sheep No.	Nitrogen in feed consumed	Nitrogen in feces	Nitrogen in urine	Nitrogen balance
	Period VI—Alfalfa hay, 800 grams			
	grams	*grams*	*grams*	*grams*
B1	25.20	5.58	15.00	+ 4.62
B2	25.20	5.17	14.43	+ 5.60
B3	25.20	4.94	15.94	+ 4.32
R1	24.40	5.95	13.98	+ 4.47
R2	24.40	5.44	14.29	+ 4.67
R3	15.25	3.57	10.63	+ 1.05
Average	23.28	5.11	14.05	+ 4.12
	Period VII—Alfalfa hay, 800 grams, and whole soybeans, 225 grams			
B1	36.85	7.52	23.56	+ 5.77
B2	36.85	6.70	23.46	+ 6.69
B3	36.85	6.82	23.46	+ 6.57
R1	39.89	7.87	23.31	+ 8.71
R2	39.89	7.12	24.00	+ 8.77
R3	39.89	6.77	23.87	+ 9.25
Average	38.37	7.13	23.61	+ 7.63
	Period VIII—Alfalfa hay, 800 grams, and soybean oil meal, 112 grams			
B1	37.63	6.78	20.77	+10.08
B2	37.63	6.40	19.50	+11.73
B3	37.63	6.30	20.16	+11.17
R1	28.77	7.89	19.32	+ 1.56
R2	27.54	7.34	17.82	+ 2.38
R3	27.54	7.23	20.46	− .15
Average	32.79	6.99	19.67	+ 6.13
	Period IX—Alfalfa hay, 800 grams, and soybean oil meal, 340 grams			
B1	41.34	8.18	29.64	+ 3.52
B2	41.34	8.54	28.47	+ 4.33
B3	41.34	8.26	32.76	+ .32
R1	41.68	10.34	27.28	+ 4.06
R2	37.62	8.51	25.55	+ 3.56
R3	37.62	7.86	24.42	+ 5.34
Average	40.16	8.62	28.02	+ 3.52
	Period X—Soybean oil meal, 450 grams			
R3	28.22	2.64	23.01	+ 2.57

TABLE 22.—A COMPILATION OF THE RESULTS OF AMERICAN AND FOREIGN EXPERIMENTS ON THE DIGESTIBILITY OF SOYBEAN PRODUCTS

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
1884	Soybean fodder (dry), 20 pounds, (with corn meal, 4 pounds, and wheat bran, 4 pounds)	Cows (2)	....	....	70	82	54	58	*days* 1	(4*)
1893	Soybean hay, 1,200 grams	Goat	62	....	70	71	19	62	5	(6*)
	Soybean hay, 16 pounds	Cow	63	....	72	66	40	60		
		Average	62.5	....	71.0	68.5	29.5	61.0		
1912	Soybean hay, 400 grams (with English hay, 400 grams)	Sheep 5	52	....	71	55	54	49	7	(6*)
		Sheep 6	61	....	79	65	65	56		
		Average	56.5	....	75.0	60.0	59.5	52.5		
1923	Soybean hay, 910 grams	Sheep 130	52	....	69	62	67	33	7	H.M.K.
		Sheep 131	56	....	69	67	69	34		
		Sheep 132	58	....	73	65	63	41		
	Soybean hay, 1,025 grams	Sheep 133	56	....	68	65	51	42		
		Sheep 134	52	....	65	64	39	36		
		Sheep 135	55	....	70	67	52	35		
	Soybean hay, 1,135 grams	Sheep 137	49	....	64	62	63	33		
		Sheep 138	55	....	69	66	63	39		
		Sheep 139	54	....	68	67	69	33		
	Soybean hay, 1,135 grams	Sheep 136	53	....	70	63	67	24		
		Sheep 140	54	....	70	61	69	32		
		Sheep 141	56	....	73	61	71	35		
		Average	54.1	....	69.0	64.2	61.9	34.8		
....	Soybean hay, average (American), 4 kinds, 18 ruminants	....	55.5	....	70.0	66.2	57.2	42.2		
1883 (German)	Soybean hay, 1 kilogram	Sheep 1	56	60	65	64	14	57	8	(3*)
		Sheep 2	55	58	63	59	14	58		
		Average	55.5	59.0	64.0	61.5	14.0	57.5		
....	Soybean hay, average (American and German), 5 kinds, 20 ruminants	....	55.5	....	69.4	65.7	52.9	43.8		

NOTE—In this table all German investigations are so marked; all others are American experiments. The initials H. M. K. in the reference column of this table refer to the authors of this bulletin.

TABLE 22.—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1923	Soybean straw, 1,135 grams	Sheep 130	41	....	9	48	−4	43	7	H.M.K.
		Sheep 131	42	....	−7	52	15	43		
		Sheep 132	39	....	18	44	12	41		
		Sheep 133	41	....	26	58	14	25		
		Sheep 134	42	....	16	55	47	33		
		Sheep 135	45	....	30	61	25	30		
		Sheep 136	36	....	12	51	3	27		
		Sheep 137	41	....	20	56	13	30		
		Sheep 138	40	....	11	54	21	32		
		Sheep 139	40	....	10	54	3	31		
		Sheep 140	38	....	5	56	0	26		
		Sheep 141	40	....	24	57	26	21		
		Average	40.4	....	14.5	53.8	14.6	31.8		
....	Soybean straw, average (American), 1 kind, 12 sheep	.....	40.4	....	14.5	53.8	14.6	31.8		
1879 (German)	Soybean straw, 1 kilogram, air-dried	Wether 1	56	59	62	71	64	32	8	(1*)
		Wether 2	54	57	60	68	61	35		
		Average	55.0	58.0	61.0	69.5	62.0	33.5		
1883 (German)	Soybean straw, 1 kilogram, air-dried	Wether 1	49	52	41	62	58	42	8	(2*)
		Wether 2	50	52	37	63	60	43		
		Average	49.5	52.0	39.5	62.5	59.0	42.5		
....	Soybean straw, average (American and German), 3 kinds, 16 sheep	.....	43.4	....	23.4	56.9	26.1	33.4		
1894	Soybeans (ground), 250 grams (with English hay, 600 grams)	Sheep 3	78	....	90	76	81	48	7	(7*)
		Sheep 4	86	....	92	77	90	94		
		Average	82.0	....	91.0	76.5	85.5	71.0		
1895	Soybeans, .5 pound (with timothy rowen hay, 1 pound)	Sheep (4)	....	....	85.1	73.6	86.6	....	5	(8**)
1895	Soybeans, same as above, .75 pound (with timothy rowen hay, 1.5 pounds)	Sheep (4)	....	....	86.6	73.1	83.2	....	5	(8**)

TABLE 22.—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1901	Soybeans, meal, 5 pounds (with kafir corn stover, 5 pounds)	Steer 1	79	....	90	68	98	(−125)	7	(9*)
1903	Soybeans, meal, 200 grams, (with English hay, 700 grams)	Sheep 2	95	....	93	93	96	195	7	(10*)
		Sheep 3	87	....	89	89	91	85		
		Average	91.0	....	91.0	91.0	93.5	140.0		
1904	Soybeans, ground, 200 grams (with English hay, 700 grams)	Sheep 2	98	....	95	103	97	122	7	(11*)
		Sheep 3	81	....	88	61	89	105		
		Average	89.5	....	91.5	82.0	93.0	113.5		
1923	Soybeans, whole, 230 grams (with oat straw, 910 grams)	Sheep 130	48	....	85	68	82	−247	7	H.M.K.
		Sheep 131	51	....	88	54	86	−215		
		Sheep 132	40	....	82	53	83	−307		
		Sheep 133	49	....	90	−16[a]	81	−58		
	Soybeans, whole, 230 grams (with oat straw, 811.4 grams)	Sheep 134	32	....	84	−62[a]	87	−113		
		Sheep 135	49	....	89	17	70	−88		
	Soybeans, whole, 225 grams (with oat straw, 680 grams)	Sheep 136	47	....	94	20	92	−166		
		Sheep 137	52	....	92	43	73	−110		
		Sheep 138	54	....	97	26	81	−101		
		Sheep 139	63	....	94	39	77	−40		
		Sheep 140	75	....	94	74	96	−61		
		Sheep 141	74	....	93	53	100	−33		
		Average	52.8	....	90.2	44.7	84.0	−128.3		
1925	Soybeans, whole, 225 grams (with alfalfa, 800 grams)	Sheep B1	84	....	82	86	89	88	10	H.M.K.
		Sheep B2	87	....	89	77	93	94		
		Sheep B3	84	....	88	74	89	88		
		Sheep R1	75	....	85	79	95	−90		
		Sheep R2	80	....	90	79	95	−77		
		Sheep R3	94	....	95	94	102	10		
		Average	84.0	....	88.0	82.0	94.0	19.0		
....	Soybeans, average (American), 8 kinds, 33 ruminants	.....	69.7	....	88.9	67.4	87.6	....		

[a]Omitted from the average.

TABLE 22—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1884 (German)	Soybeans, ground, 250 grams (with hay, 750 grams)	Buck 1	84	86	88	63	95	177	8	(3*)
		Buck 2	82	84	87	61	93	160		
		Average	83.0	85.0	87.5	62.0	94.0	168.5		
....	Soybeans, average (American, and German), 9 kinds, 35 ruminants	.....	70.0	....	88.9	67.1	88.0	....		
1914	Soybeans, 209 grams (with corn, 1,046 grams)	Swine 1	....	....	94	92	86	34	10	(12*)
	Soybeans, 345 grams (with corn, 1,727 grams)	Swine 2	....	....	90	113	74	27		
	Soybeans, 299 grams (with corn, 1,494 grams)	Swine 3	....	....	98	101	90	36		
	Soybeans, 220 grams (with corn, 1,097 grams)	Swine 4	....	....	94	96	93	30		
	Soybeans, 284 grams (with corn, 1,422 grams)	Swine 5	....	....	92	104	75	20		
		Average	....	....	93.6	101.2	83.6	29.4		
....	Soybeans, average (American), 1 kind, 5 swine	.....	....	....	93.6	101.2	83.6	29.4		
1923	Soybean oil meal, 225 grams, extracted (with soybean straw, 910 grams)	Sheep 130	102	....	86	109	80	178	7	H.M.K.
		Sheep 131	107	....	88	90	92	323		
		Sheep 132	110	....	89	94	92	326		
		Sheep 133	115	....	89	124	118	258		
		Sheep 134	111	....	85	126	64	247		
		Sheep 135	110	....	87	137	72	132		
		Sheep 136	120	....	81	127	97	393		
		Sheep 137	132	....	86	149	67	436		
		Sheep 138	130	....	84	124	107	534		
		Sheep 139	101	....	92	77	117	285		
		Sheep 140	109	....	93	89	120	333		
		Sheep 141	121	....	96	96	112	431		
		Average	114.0	....	88.0	111.8	94.8	323.0		

TABLE 22.—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1925	Soybean oil meal, 112 grams, extracted (with alfalfa hay, 800 grams)	Sheep B1	80	....	98	97	100	−270	10	H.M.K.
		Sheep B2	73	....	104	76	100	−280		
		Sheep B3	86	....	107	103	90	−250		
		Sheep R1	49	....	55	76	17	0		
		Sheep R2	36	....	59	81	50	−90		
		Sheep R3	10	....	57	53	24	−230		
		Average	56	....	80	81	64	−187		
1925	Soybean oil meal, 228 grams, extracted (with soybean oil meal, 112 grams, and alfalfa hay, 800 grams)	Sheep B1	74	....	84	94	91	116	10	H.M.K.
		Sheep B2	73	....	82	92	100	116		
		Sheep B3	72	....	85	92	81	127		
		Sheep R1	62	....	71	86	75	135		
		Sheep R2	44	....	76	81	109	−47		
		Sheep R3	57	....	80	81	119	71		
		Average	64	....	80	88	96	86		
1925	Soybean oil meal, 450 grams, extracted	Sheep R3	81	....	90	82	74	55	10	H.M.K.
....	Soybean oil meal, average (American), 2 kinds, 24 sheep	.....	86.8	....	84.3	97.5	86.9	....		
1909 (German)	Soybean oil meal (pressed), 240 grams (with clover hay, 760 grams)	Wether 1	....	90	92	98	94	17	10	(23*)
		Wether 2	....	97	94	108	92	55		
		Average	....	93.5	93.0	103.0	93.0	36.0		
1909 (German)	Soybean oil meal, extracted, 200 grams (with clover hay, 600 grams, for Wether 2), 200 grams (with hay, 700 grams, for Wether 4)	Wether 2	....	97	92	113	30	68	10	(23*)
		Wether 4	....	96	92	98	106	130		
		Average	....	96.5	92.0	105.5	68.0	99.0		
....	Soybean oil meal, average (German), 3 kinds, 4 sheep	.....	....	95.0	92.5	104.3	80.5	67.5		
....	Soybean oil meal, average (American and German), 5 kinds, 29 sheep	.....	86.8	....	85.4	98.4	86.0	....		

TABLE 22.—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1909 (German)	Soybean oil meal, fat-free, 300 grams (with pressed potatoes, 1,100 grams)	Swine 1	....	91	94	94	....	60	10	(28*)
		Swine 2	....	90	94	91	....	61		
		Average	....	90.5	94.0	92.5	....	60.5		
	Soybean oil meal (reported by Honcamp from Japanese)[a]	.....	87	90	88	90	82	131	(?)	(23*)
	Soybean oil meal (reported by Honcamp from "Monatsheften für Landwirtschaft" 1909, p. 341)[a]	.....	....	....	91	92	90	67	(?)	(23*)
1892	Soybean silage, 2,721.6 grams, fresh	Goat	52	....	71	46	66	47	5	(16*)
		Goat	66	....	80	58	77	62		
		Average	59	....	75.5	52.0	71.5	54.5		
1895	Soybean silage, 64 pounds, fresh	Steer 53	50	54	55	61	47	44	6	(17*)
	Soybean silage, 62 pounds, fresh	Steer 54	50	54	55	61	49	42		
	Soybean silage, 66 pounds, fresh	Steer Roan	49	53	55	61	48	42		
	Soybean silage, 48 pounds, fresh	Steer 57	50	54	56	61	53	43		
		Average	49.8	53.8	55.3	61.0	49.3	42.8		
1903	Soybean silage (all the sheep would consume)	Sheep 1	....	63	58	74	48	51	5	(18*)
		Sheep 3	....	73	69	80	60	67		
		Sheep 4	....	66	57	75	50	59		
		Average	....	67.3	61.3	76	52.7	59.0		
....	Soybean silage, average (American), 3 kinds, 9 ruminants	.....	52.8	....	61.8	64.1	55.3	50.8		
1895	Soybean fodder (green), 6 pounds (in bloom)	Sheep C	....	65	81	71	58	45	5	(3*)
		Sheep E	....	68	77	73	50	56		
		Average	....	66.5	79.0	72.0	54.0	50.5		
1895	Soybean fodder (green), 6 pounds, 3 ounces (same as above except more advanced, seeds formed)	Sheep B	....	61	71	72	59	39	5	(3*)
		Sheep F	....	64	68	75	49	43		
		Average	....	62.5	69.5	73.5	54.0	41.0		
1896	Soybean fodder (green), 2,340 grams (early to full bloom)	Sheep C	....	63	78	73	54	46	5	(13*)
		Sheep D	....	62	77	69	46	49		
		Average	....	62.5	77.5	71.0	50.0	47.5		

[a]Omitted from the average.

TABLE 22.—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1896	Soybean fodder (green), 2,340 grams (bloom to early seed)	Sheep B	....	68	74	77	62	49	5	(13*)
		Sheep F	....	67	76	75	54	50		
		Average	....	67.5	75.0	76.0	58.0	49.5		
1897	Soybean fodder (green), 3,000 grams	Sheep A	....	....	76	79	35	39	5	(14*)
		Sheep B	....	....	78	81	46	44		
		Sheep C	....	....	74	76	33	44		
		Sheep D	....	....	77	79	31	50		
		Average	....	....	76.3	78.8	36.3	44.3		
1903	Soybean fodder (green), 2,000 grams (with English hay, 400 grams)	Sheep 1	64	....	84	76	66	40	7	(11*)
		Sheep 2	63	....	82	79	66	31		
		Sheep 3	65	....	82	78	64	46		
		Average	64.0	....	82.7	77.7	65.3	39.0		
1904	Soybean fodder (green), 1,800 grams (with English hay, 350 grams)	Sheep 1	69	....	81	78	69	53	7	(15*)
		Sheep 2	64	....	80	74	65	47		
		Sheep 3	62	....	80	71	68	43		
		Average	65.0	....	80.3	74.3	67.3	47.7		
....	Soybean fodder (green), average (American), 7 kinds, 18 sheep	.....	....	....	77.6	75.3	54.2	45.2		
1879	Soybean pods, 1,000 grams, air-dried	Wether 1	63	63	46	73	59	52	8	(1*)
		Wether 2	61	62	43	73	55	50		
		Average	62.0	62.5	44.5	73.0	57.0	51.0		
1895	Soybean meal, .5 pound, and timothy rowen hay, 1 pound	Sheep A	....	....	76	67	71	61	5	(3*)
		Sheep B	....	....	77	69	77	61		
		Sheep C	....	....	80	68	77	63		
		Sheep E	....	....	76	61	71	57		
		Average	....	....	77.3	66.3	74.0	60.5		
1895	Soybean meal, .75 pound, and timothy rowen hay, 1.5 pound	Sheep A	....	....	77	62	74	60	5	(3*)
		Sheep B	....	....	77	67	73	63		
		Sheep C	....	....	79	64	72	56		
		Sheep E	....	....	80	72	73	70		
		Average	....	....	78.3	66.3	73.0	62.3		

TABLE 22—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficients						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
									days	
1896	Corn and soybean silage, 2:1, 1,600 grams (with English hay, 400 grams)	Sheep 1	66	....	65	73	83	59	7	(19)*
		Sheep 2	69	....	63	74	80	65		
		Sheep 4	72	....	67	78	84	71		
		Average	69.0	....	65.0	75.0	82.3	65.0		
1896	Millet and soybean silage, 1,600 grams (with English hay, 400 grams)	Sheep 1	54	....	58	51[b]	76	57[b]	7	(19*)
		Sheep 2	58	....	55	56	72	64		
	Millet and soybean silage, 1,800 grams (with English hay, 400 grams)	Sheep 3	58	....	42[b]	59	69	70		
		Sheep 4	65	....	62	63	80[b]	74		
		Average	58.8	....	(54.3)	(57.3)	(74.3)	(66.3)		
1901-04	Soybean-corn silage, 9:14, 3,000 grams	Sheep 1	70	72	67	74	89	62	6	(20*)
	Soybean-corn silage, 9:14, 2,000 grams	Sheep 2	73	75	68	79	91	68		
		Average	71.5	73.5	67.5	76.5	90.0	65.0		
1901-04	Soybean-corn silage, 9:14, 54.2 pounds	Steer 2	71	72	56	81	67	62	6	(20*)
1901-04	Soybean-corn silage, 9:14, 40 pounds (with hay, 5 pounds)	Steer 1	69	71	54	80	....	51	6	(20*)
	Soybean-corn silage, 9:14, 40 pounds (with hay, 10 pounds)	Steer 2	62	72	62	80	88	60		
		Average	65.5	71.5	58.0	80	88.0	55.5		
1923	Soybeans, whole, 230 grams, and oat straw, 910 grams	Sheep 130	46	....	66	48	63	38	7	H.M.K.
		Sheep 131	47	....	70	46	67	40		
		Sheep 132	45	....	63	46	64	35		
	Soybeans, whole, 230 grams, and oat straw, 811 grams	Sheep 133	47	....	69	37	63	49		
		Sheep 134	42	....	69	28	70	42		
		Sheep 135	47	....	73	40	58	41		
		Average	45.7	....	68.3	40.8	64.2	40.8		

[b]Omitted from the average by Lindsey; included in above average.

TABLE 22—*Continued*

Year of experiment	Daily ration	Animal	Digestion coefficient						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
1923	Soybeans, whole, 225 grams, and oat straw, 800 grams	Sheep 136	46	....	73	41	72	38	7	H.M.K.
		Sheep 137	48	....	72	45	59	42		
		Sheep 138	49	....	76	41	65	40		
		Sheep 139	51	....	73	44	63	50		
		Sheep 140	54	....	74	50	77	48		
		Sheep 141	53	....	73	46	79	51		
		Average	47.9	....	70.9	42.7	66.7	42.8		
1923	Soybean straw, 910 grams, and soybean oil meal, 225 grams	Sheep 130	53	....	66	63	51	38	7	H.M.K.
		Sheep 131	54	....	68	60	57	43		
		Sheep 132	56	....	70	61	60	46		
		Sheep 133	55	....	69	65	71	41		
		Sheep 134	54	....	66	66	42	40		
		Sheep 135	55	....	68	69	47	36		
		Sheep 136	57	....	66	67	63	44		
		Sheep 137	59	....	70	71	46	46		
		Sheep 138	59	....	69	66	69	50		
		Sheep 139	52	....	68	58	68	41		
		Sheep 140	55	....	70	61	70	44		
		Sheep 141	56	....	70	62	65	46		
		Average	55.4	....	68.3	64.1	59.1	42.9		
1925	Soybeans, whole, 225 grams, and alfalfa hay, 800 grams	Sheep B1	66	....	78	77	63	48	10	H.M.K.
		Sheep B2	66	....	80	77	63	48		
		Sheep B3	66	....	81	77	58	48		
		Sheep R1	63	....	76	74	45	47		
		Sheep R2	65	....	78	75	40	51		
		Sheep R3	63	....	77	75	34	48		
		Average	64.8	....	78.3	75.8	50.5	48.3		

TABLE 22.—*Concluded*

Year of experiment	Daily ration	Animal	Digestion coefficient						Length of collection period	Reference
			Dry matter	Organic matter	Crude protein	N-free extract	Ether extract	Crude fiber		
1925	Soybean oil meal, 112 grams, and alfalfa hay, 800 grams	Sheep B1	67	....	82	78	67	28	10	H.M.K.
		Sheep B2	66	....	83	76	55	27		
		Sheep B3	68	....	83	78	64	29		
		Sheep R1	63	....	73	76	44	48		
		Sheep R2	61	....	73	76	50	42		
		Sheep R3	58	....	74	73	48	37		
		Average	63.8	....	78.0	76.2	54.7	35.2		
1925	Soybean oil meal, 340 grams, and alfalfa hay, 800 grams	Sheep B1	67	....	80	80	67	41	10	H.M.K.
		Sheep B2	67	....	80	79	71	41		
		Sheep B3	67	....	80	79	67	42		
		Sheep R1	65	....	75	78	63	43		
		Sheep R2	62	....	77	77	75	30		
		Sheep R3	64	....	79	77	78	37		
		Average	65.3	....	78.5	78.3	70.2	39.0		